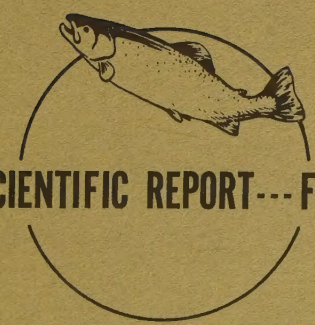
SIZE FREQUENCIES AND GROWTH OF CENTRAL AND WESTERN PACIFIC BIGEYE TUNA



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By

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ABSTRACT

Bigeye tuna (Parathunnus sibi) weight data from the Honolulu market for the period 1947-54, length data collected aboard Japanese tuna motherships in the equatorial western Pacific in 1951, and published length frequency distributions from the Japanese longline fishery in the northwest Pacific were compared and studied for evidence of growth and of local differences in the size composition of the population. In the data from both the equatorial western Pacific and Hawaiian waters the modes of the male size distributions were found to be about 14 cm. or 30 pounds larger than the corresponding female modes. Monthly weight frequencies of Hawaiian bigeye showed a consistent progression of modes, yielding a provisional growth curve that indicates that these fish may gain as much as 50 pounds in 1 year and may live about 6 or 7 years. Relatedness of the bigeye in Hawaiian waters and in the Japanese North Pacific fishery is suggested by the approximately similar growth rates and by the presence of a complementary 2-year cycle of dominant size groups in the catches of both areas. Data from equatorial waters showed no progression of the modes with time.

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The purpose of this analysis of bigeye tuna, Parathunnus sibi (Temminck and Schlegel) = P. mebachi (Kishinouye)[1/], measurements is to learn about growth and migration of this species from the size composition of commercial longline catches. Consideration of size frequencies from the Hawaiian and the Japanese North Pacific fisheries yields evidence of a relationship which suggests that there is but a single stock of bigeye being exploited by both fisheries. These data also furnish evidence of rapid growth of bigeye tuna. Other facets of the biology of the species, such as size differences associated with sex, are revealed by Japanese catches in the equatorial Pacific and Hawaiian catches. Measurements obtained on Japanese mothership expeditions in the western equatorial Pacific, which will be discussed, supply information on size differences associated with sex and evidence pointing to a migration of this species. (The size frequencies on which this study is based are presented in tabular form in the appendix.)

The bigeye tuna is of considerable importance in the Hawaiian longline (flagline) fishery, where catches are sold on the Honolulu fresh fish market. The operation of the Hawaiian fishery has been described and catch statistics analyzed by June (1950) and Otsu (1954). In 1952, a year of high abundance, the value of the landings to the fishermen is given by Otsu as $684,726. The same author also describes the seasonal trend in apparent abundance, pointing out that the lighter catches occur from June to September and the heavier catches from October to May. The catch of this species increased sharply from 126,000 pounds

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[1/] Parathunnus sibi (Temminck and Schlegel) is regarded as a synonym of P. mebachi (Kishinouye) by numerous authors, among them Brock (1949) and Nakamura (1949). For the purpose of this paper they will be considered a single species.

in 1946 to 2,193,000 pounds in 1952. The years 1953 and 1954 similarly show high catches of 2,826,000 pounds and 2,759,000 pounds respectively.[2/]

The bigeye tuna is also important in the Japanese high seas longline fishery, which covers vast areas of the western and central Pacific Ocean, extending as far east as Hawaii. Following World War II, Japanese mothership expeditions, described by Shimada (1951a and b), Ego and Otsu (1952), Van Campen (1952), and Murphy and Otsu (1954), landed considerable numbers of bigeye tuna. These expeditions operated from about 1° to 10°N. latitude and 134° to 179°E. longitude. Farther to the north there is a Japanese longline fishery for deep-swimming tunas, including bigeye, which has been described by Shapiro (1950). The area covered by this North Pacific fishery is usually north of 26°N. latitude and between 130°E. and 165°W. longitude.

ACKNOWLEDGEMENTS

Appreciation is extended to the individuals, too numerous to mention, who have aided in the collection of measurements and offered direction in preparing this report. To the Hawaii Fishing Co., Ltd., and the United Fishing Agency indebtedness is acknowledged for permission to examine sales records. To Mr. T. Nakata thanks are extended for the preparation of figures in this report.

MATERIAL AND METHODS

For most of the Hawaiian specimens only the weight (obtained from market sales slips) is available. Length measurements taken on the Japanese mothership expeditions were in millimeters from the tip of the snout with jaws closed to the median portion of the caudal fork (with fleshy flap depressed) as described by Marr and Schaefer (1949). Additional length frequencies were obtained from Japanese reports. Prior to analysis length measurements were tabulated in 2-centimeter intervals, and weight measurements in 10-pound intervals. When it was necessary to convert from length to weight, the relationship log weight (pounds) = -7.1167 + 2.9304 log total length (millimeters), based on Hawaiian samples, was used. To smooth data, a moving average of three was applied.

[2/] From unpublished records of the Division of Fish and Game, Board of Commissioners of Agriculture and Forestry, Territory of Hawaii.

Since the successful interpretation of growth from time series of size frequency distributions depends on an objective and realistic method of locating modes, the following criteria were adopted:

1. No modes have been sought in distributions containing less than 100 fish.

2. Each mode must be separated from every other mode by troughs dipping at least 5 fish below modes after smoothing.

3. Each mode must be present in the data for at least two not too widely separated months.

4. At least two of the groups making up the mode must have no less than 15 individuals each before smoothing, or at least 10 individuals if the modal peak is present in two adjacent months.

5. The mode must be the center group of a peak of the smoothed distribution or the center group of two or more minor peaks which differ by less than 5 fish in height.

SIZE DIFFERENCE BY AREAS

Bigeye tuna taken on commercial longline gear are smaller in the western than in the central Pacific (Kamimura and Honma 1953, Murphy and Shomura 1953b, and Murphy and Otsu 1954). In their report, Murphy and Shomura state that longline fishing west of 180° longitude yielded bigeye that averaged about 40 pounds lighter in weight than those taken between 180° and 120°W. longitude. This interesting phenomenon is believed by them to be related to ecological conditions, however, Iversen[3/] points out that this type of size segregation can be the result of migration.

SEXUAL DIFFERENCE IN CATCH

The bigeye males achieve a larger average size than the females, for all recognizable male modes are to the right of the corresponding female modes. Size distributions from the Hawaiian Islands (fig. 1) and the western Pacific (137° - 165°E. longitude) (fig. 2) show a parallel size differential between the sexes.

[3/] MS. Size variation of central and western Pacific yellowfin with age and area.

In view of this size difference it is of interest to examine the sex ratio for possible variation throughout the year. Aside from intrinsic interest, this is advisable because a periodic change in the sex ratio could shift the positions of the modes of unsexed samples and make an analysis of growth misleading. The mean percentage of males for Hawaiian bigeye for the year 1949 was 59.2 percent and for 1951, 57.5 percent (Otsu 1954). The larger samples (over 100 specimens) from these same years and December of 1950, when tabulated by months (table 1), indicate that the sex ratio remained rather constant at about 60 percent males throughout the year.

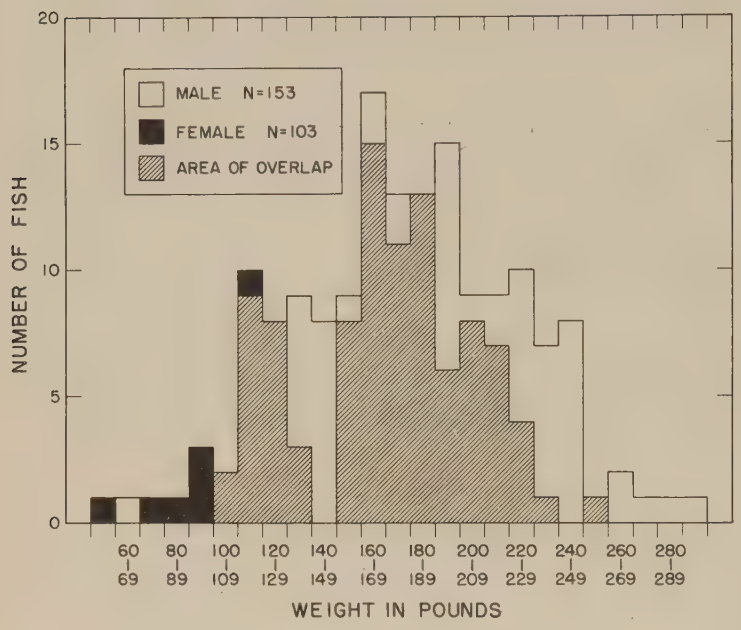

Figure 1.--Weight frequency distributions of bigeye tuna landed at the Honolulu market from May to August 1951.

The possibility that the sex ratio changes as the fish grow requires examination because this could affect the position of modes based on unsexed samples. Otsu (1954) states "....the sex ratio in the catch /fifth Japanese mothership expedition/ below 80-90 pounds is about equal, whereas the males predominate among the larger bigeye and yellowfin." However, if the female bigeye size frequency distribution is shifted a distance equal to the average growth lag between sexes, the apparent change in sex ratio with increase in fish size disappears.

Figure 3, lower panel, shows the sex ratios plotted by size groups from the data used by Otsu (fig. 2). The proportion of males increases with an increase in the size of the fish. (The small numbers in the extreme groups connected with dashed lines are better ignored.)

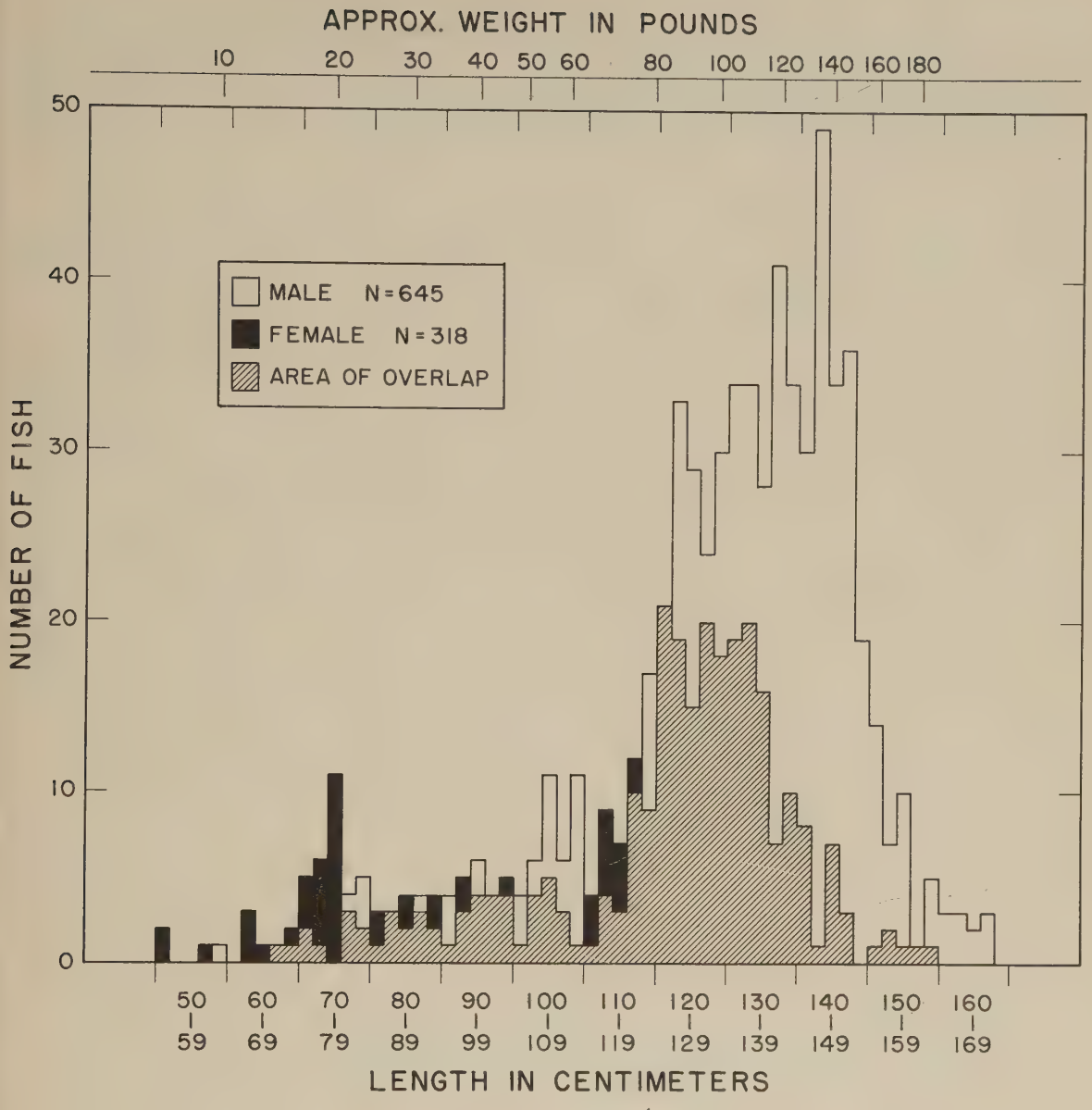

Figure 2.--Length frequency distributions of bigeye tuna from 137°- 165°E. longitude taken between March 29 and May 28, 1951.

In the upper panel the female size groups have been moved 14 cm. to the right (approximate average difference in size related to sex), and the resultant trend indicates that the sex ratio is constant at about 60 percent males throughout the size range studied.

Table 1.--Monthly sex ratio of Hawaiian bigeye tuna

Months	Males	Females	Total	Percent Males
1949				
Jan.-Feb.	32	18	50	64.0
Mar.	16	16	32	50.0
Apr.	5	10	15	33.3
May	7	3	10	70.0
June-Aug.	10	1	11	90.9
Sept.	30	11	41	73.2
Oct.	41	35	76	53.9
Nov.	100	65	165	60.6
Dec.	105	79	184	57.1
Total	346	238	584	59.2
1950				
Nov.	5	9	14	35.7
Dec.	102	59	161	63.4
1951				
Jan.	38	24	62	61.3
Feb.	24	25	49	49.0
Mar.	42	57	99	42.4
Apr.	65	39	104	62.5
May	82	43	125	65.6
June	51	34	85	60.0
July	57	50	107	53.3
Aug.	35	25	60	58.3
Sept.	40	43	83	48.2
Oct.	89	70	159	56.0
Total	630	478	1108	56.9

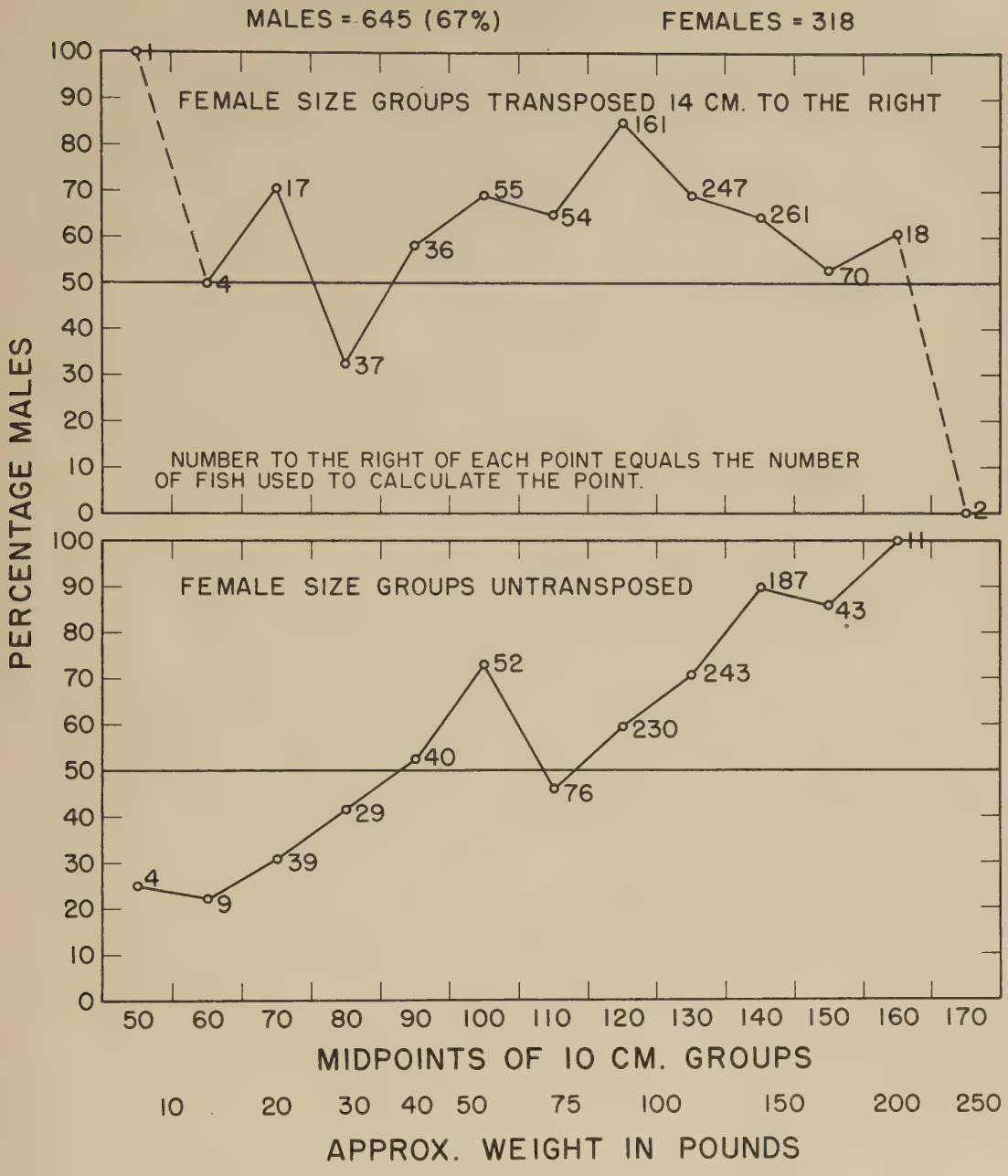
MALES = 645 (67%)
FEMALES = 318
FEMALE SIZE GROUPS TRANSPOSED 14 CM. TO THE RIGHT
NUMBER TO THE RIGHT OF EACH POINT EQUALS THE NUMBER OF FISH USED TO CALCULATE THE POINT.
FEMALE SIZE GROUPS UNTRANSPOSED
PERCENTAGE MALES
MIDPOINTS OF 10 CM. GROUPS
APPROX. WEIGHT IN POUNDS

Figure 3.--Percentage bigeye tuna males in sample by size groups. Sample from 137°-165°E. longitude taken between March 29 and May 28, 1951. Lower panel shows the sex ratios of each size class of the sample in figure 2 (same data used by Otsu (1954)).

INTERYEAR SIZE DIFFERENCES

Before examining size distributions for evidence of growth, it is important to look for groups of similar sizes that appear each year. If detected in the same position year after year these dominant groups can be looked upon as the progeny of annual spawnings (year classes). To make this interyear comparison, monthly Honolulu market weights from November 1947 through December 1954 were plotted as weight frequency graphs (figs. 4-11).

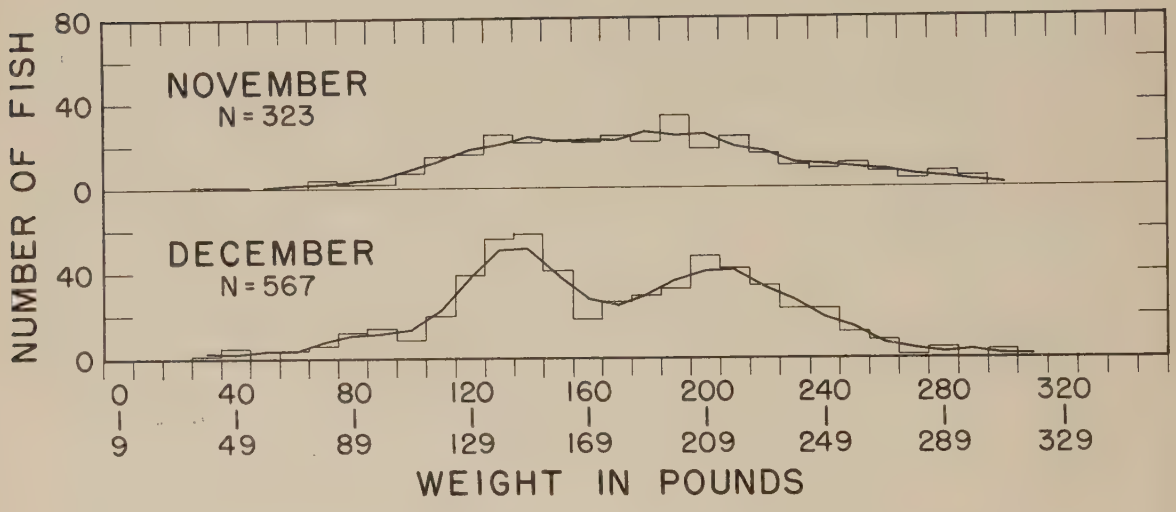

Figure 4. --Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1947.

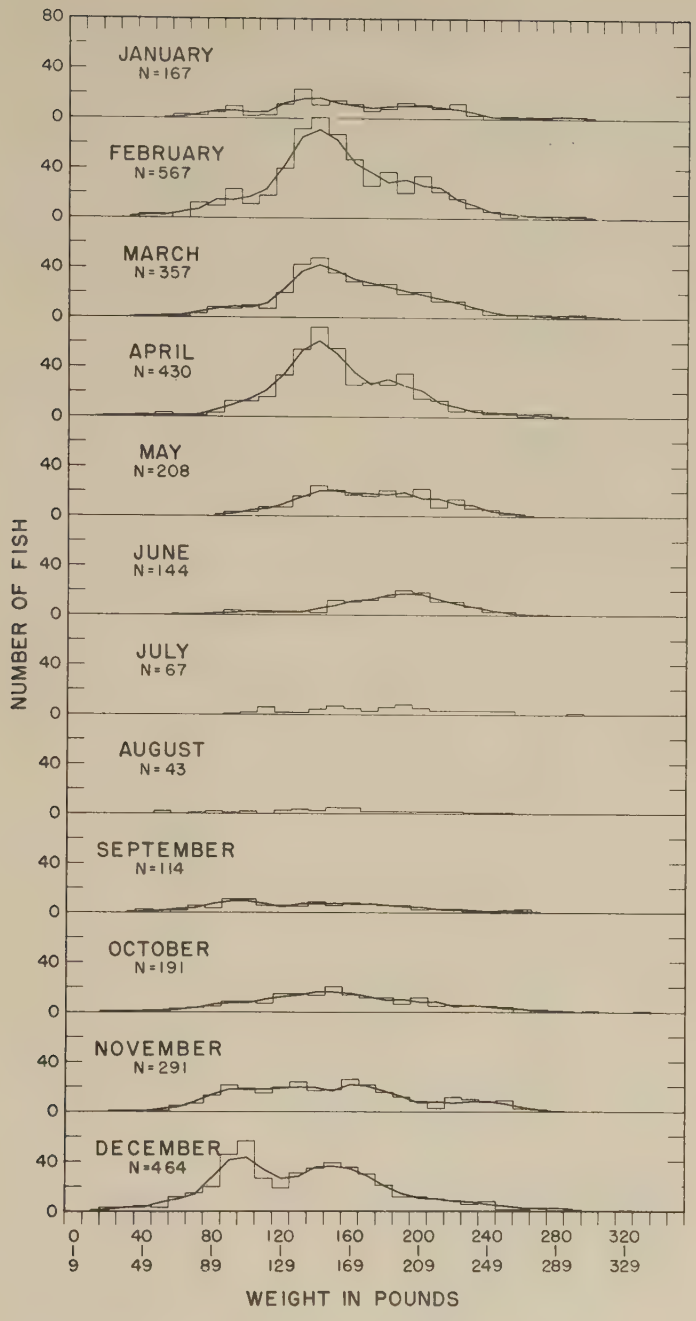

Figure 5.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1948.

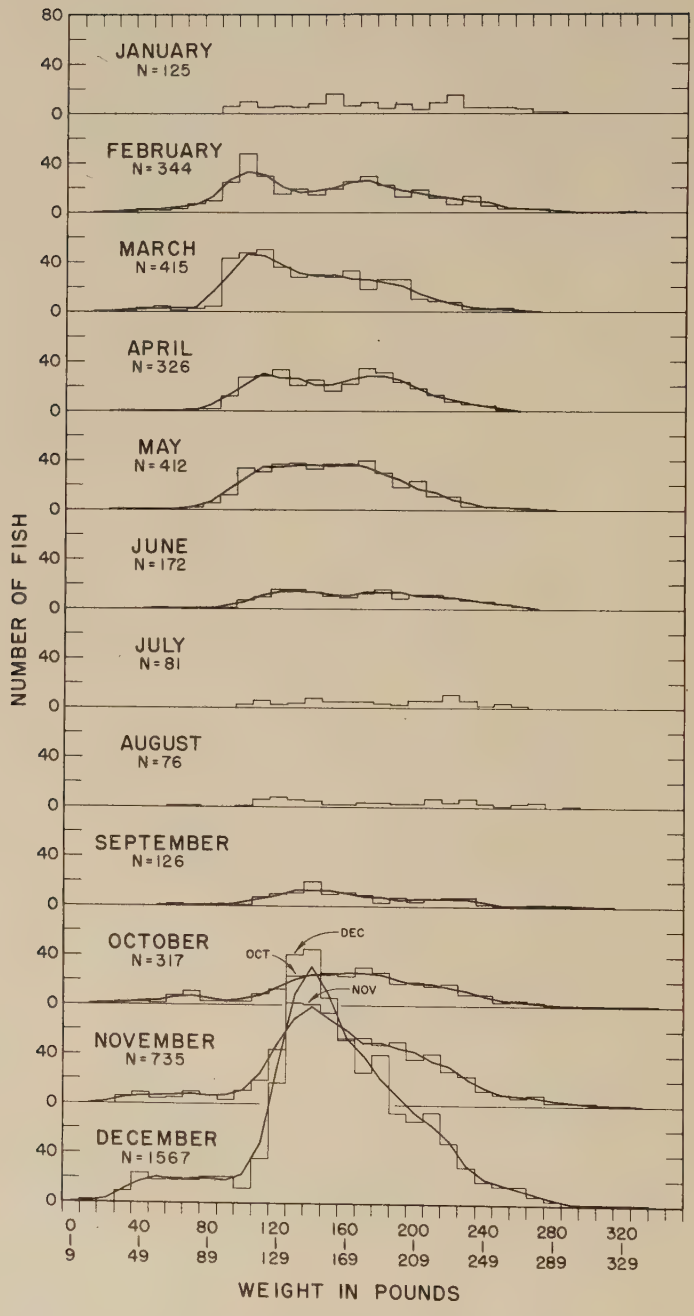

Figure 6.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1949.

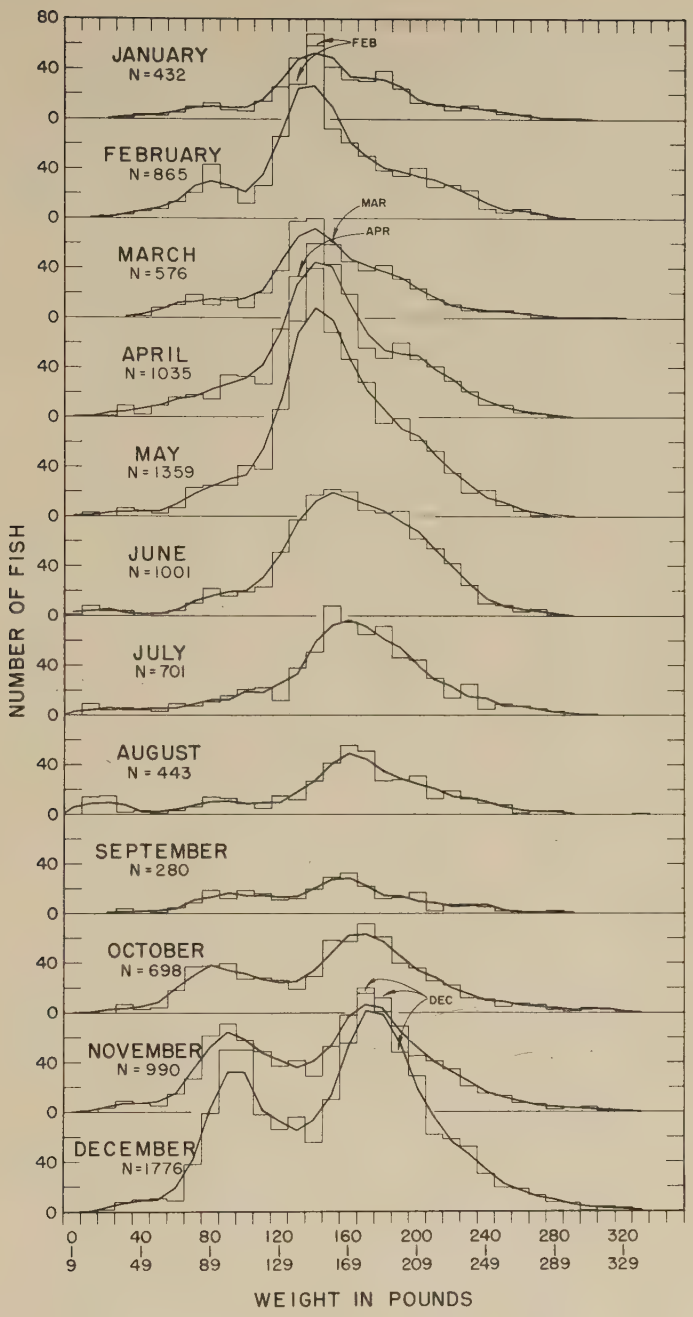

Figure 7.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1950.

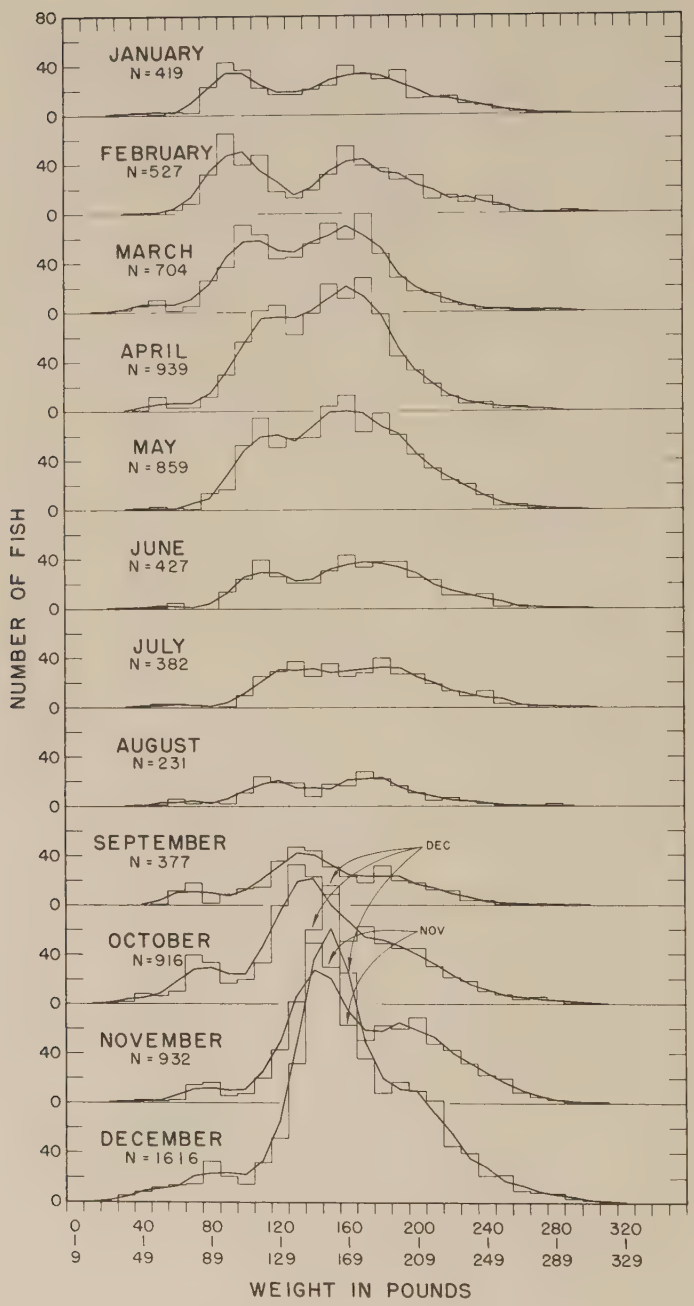

Figure 8.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1951.

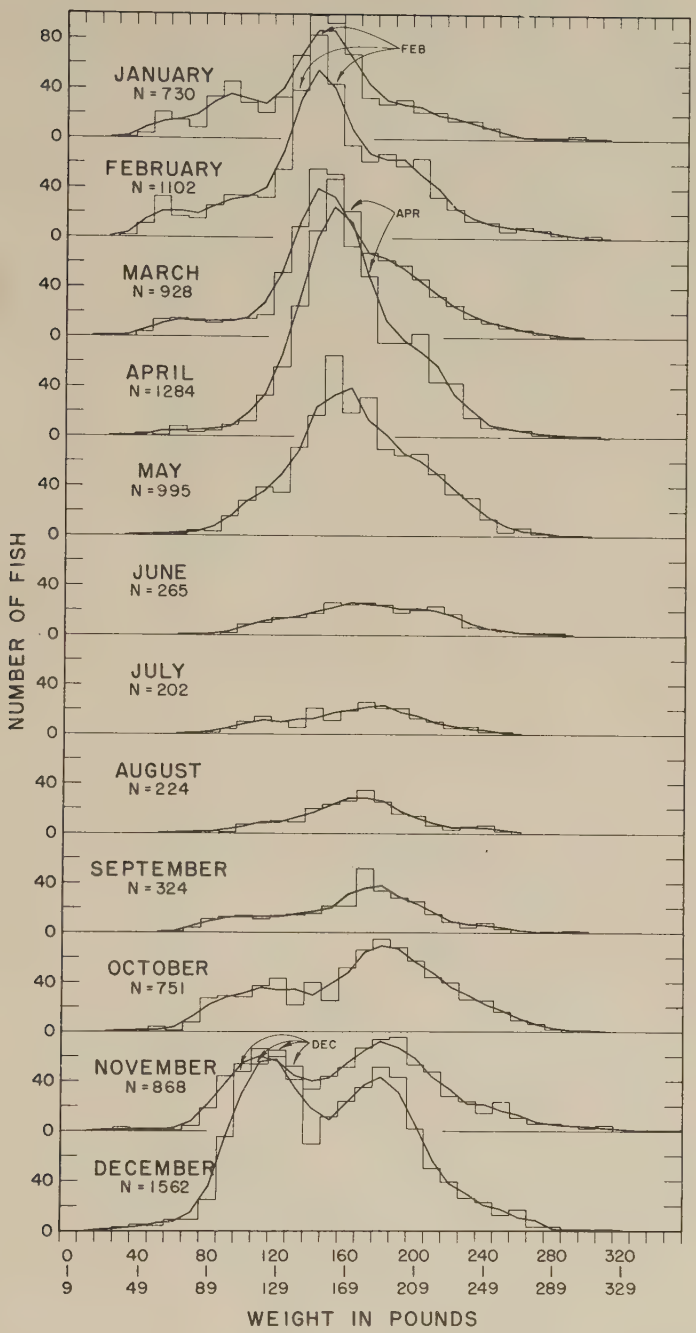

Figure 9.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1952.

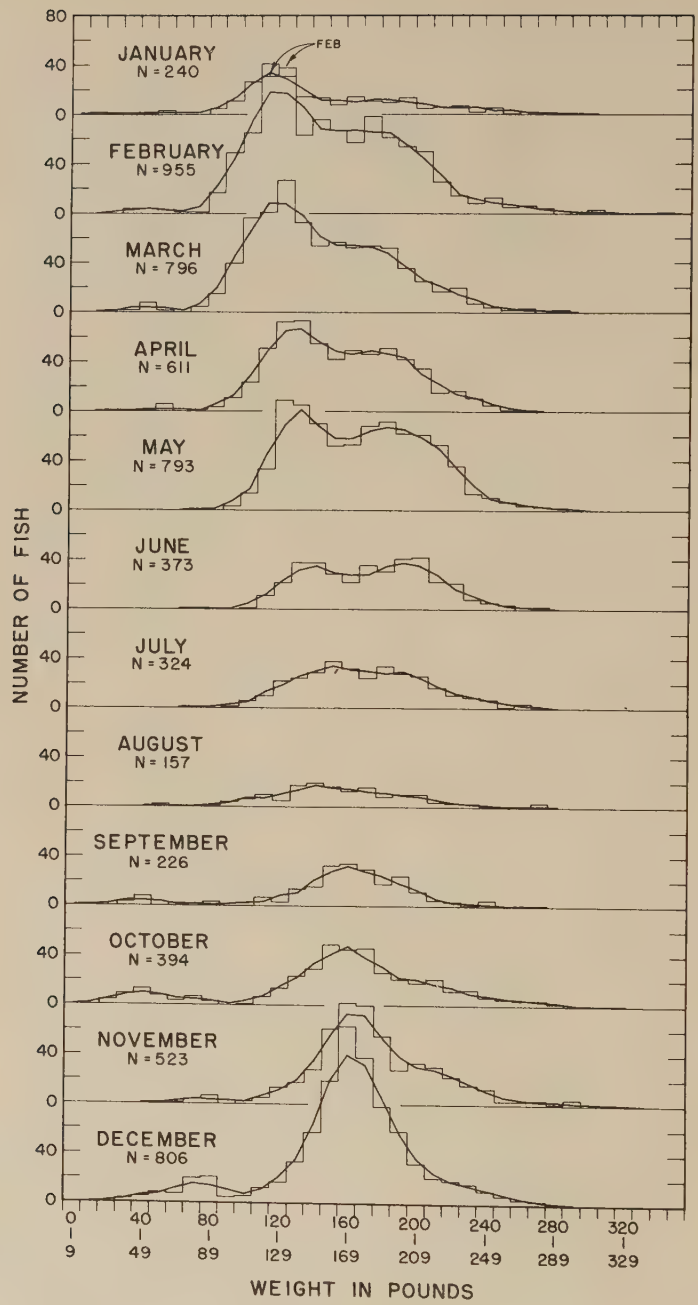

Figure 10.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1953.

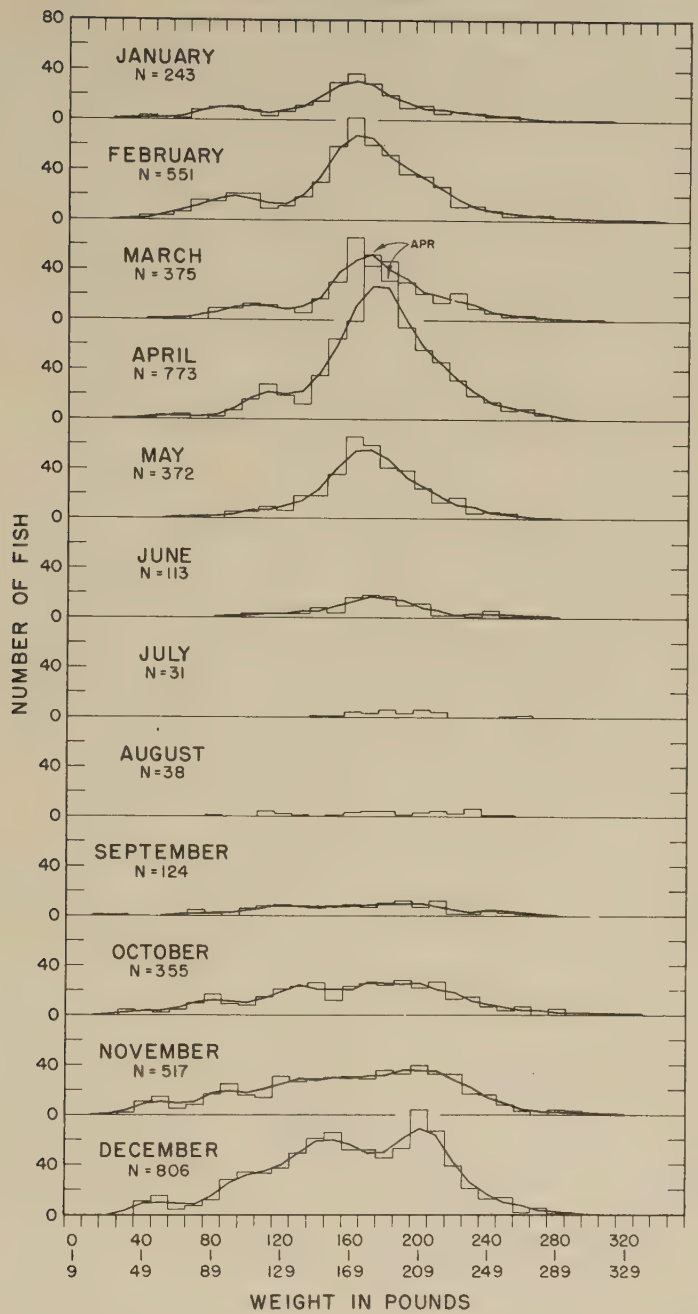

Figure 11.--Monthly weight frequency distributions of bigeye tuna from the Honolulu market for 1954.

An interesting aspect of these graphs is the noticeable difference in the positions of the dominant modes between adjacent years. For example, the year 1952 (fig. 9) has a dominant mode at about 150 pounds in January that progresses to 185 pounds by December and a secondary mode beginning at about 95 pounds in January that moves to about 120 pounds in December. The year 1953 (fig. 10), on the other hand, has but a single dominant mode, which is apparent for nearly all months of the year. This can be seen at about 115 pounds in January and progresses to about 165 pounds in December. In comparing the same month there is no evidence of similarly situated dominant modes in the 1952 and 1953 data. This lack of agreement between the dominant modal size groups of adjacent years holds true for all years examined.

There are, however, strong resemblances between the distributions of sizes in alternate years. To illustrate the differences between adjacent years and the resemblances of alternate years, December samples of all available years (1947-1954) have been plotted as percentage weight frequencies in figure 12. It is self-evident that there is a persistent difference between but a similarity within the series of odd- and even-numbered years. This points to a cycle of dominant weight groups with a period of about 2 years.

Dominant modes are not found in exactly the same position each second year, but increase in size (fig. 12). Looking at odd-numbered years first, in December 1947 the dominant mode was centered at 140 pounds, but by December 1953 it had progressed to 165 pounds. For the even-numbered years there are two dominant modal groups that act similarly. A small dominant mode at 105 pounds in the December 1948 sample can be traced through each even-numbered year until it reaches 150 pounds in December 1954. A larger dominant mode that occurred at 155 pounds in 1948 can be seen progressing through all the December samples of even-numbered years, reaching 205 pounds in the 1954 sample.

An average of less than 24 months elapses between the appearance of dominant size groups in the Hawaiian fishery. This is indicated by the "growth lines" fitted by eye (fig. 13) to the modes from the monthly distribution (figs. 5-11, table 2), and by the increasing size of apparently homologous modes as they reappear in the fishery every 2 years (fig. 12). If these modes represent year classes, this could mean that the peak of spawning or spawning survival takes place a little later every second year, which seems unlikely. It is more to be expected that spawning recurs at about the same time each year and

that the increase in the size of the dominant modes (of both the even- and odd-numbered years) from 1947 to 1954 is related to some other change in the population.

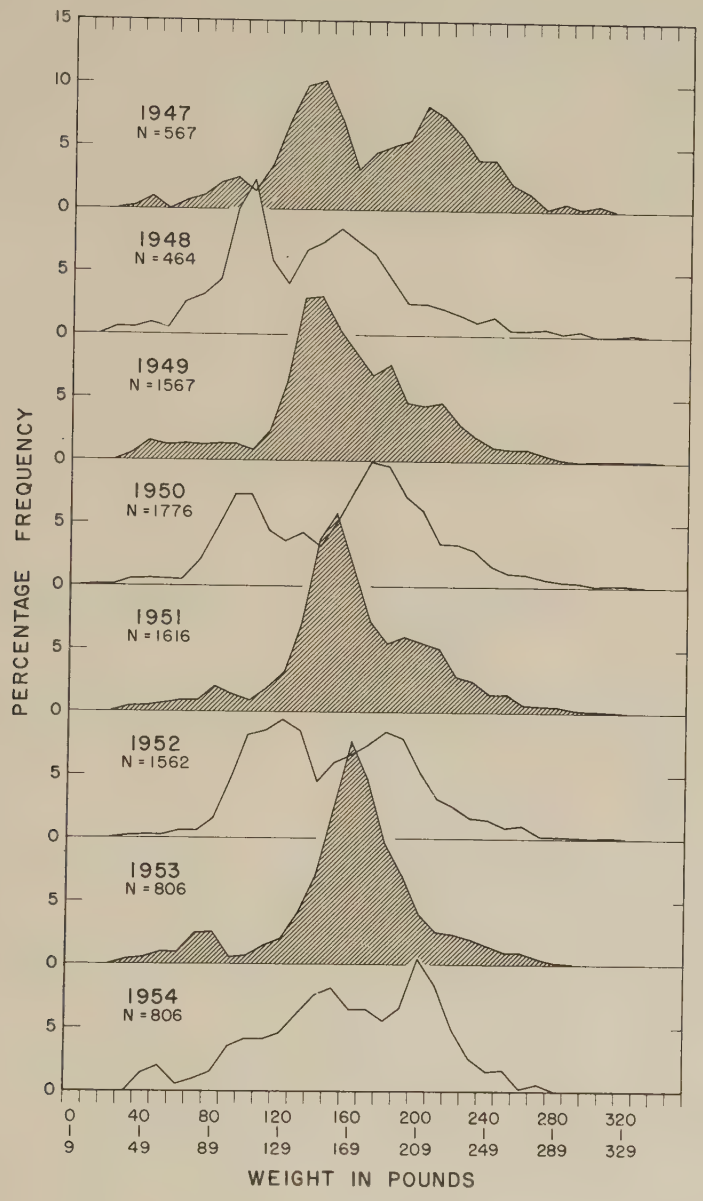

Figure 12.--Hawaiian bigeye tuna weight frequency distributions (percentage) for December samples, 1947 to 1954.

The alternate-year occurrence of certain size groups also takes place in the western Pacific (fig. 14) and it is enlightening to compare the modes of bigeye tuna from the two regions. Kamimura and Honma (1953) and Nakamura et al. (1953) report a "biennial" occurrence of dominant size groups taken in the Japanese North Pacific bigeye fishery. (The sizes of their fish are given in centimeters and were converted to pounds by the Hawaiian length-weight formula.) Nakamura et al. report the modes for November 1948 to March 1949 (1948 season) and for October 1949 to April 1950 (1949 season) (see table 3). Kamimura and Honma list the ranges for all modal groups through the 1952 season and have included the data of Nakamura et al.

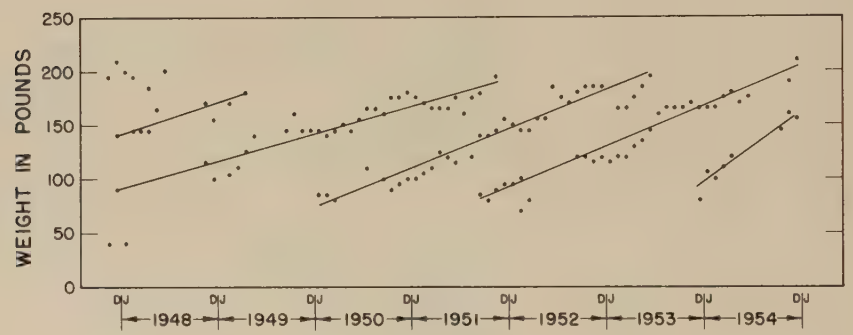

Figure 13.--"Growth lines" of Hawaiian bigeye tuna as determined by modal values, based on the locations of modes in figures 5-11.

Where the Japanese investigators have not indicated modes, they have been selected from their data. Thus modes are available for each of five fishing seasons (1948-1952) (table 3). These modes, plotted as fishing season midpoints on figure 15, together with the growth lines from the Hawaiian fishery (fig. 13), show that modes in the Japanese fishery alternate with those of the Hawaiian fishery within a year, and that the slopes of the "growth lines" for both areas are very similar.[4/] The similarities in the slopes of the growth lines and the presence of complementary cycles of approximately 2 years suggest that the same bigeye population contributes to both fisheries.

[4/] The modes in the Japanese landings have been connected by the present author.

Table 2.--Time and position of observed modal mid-points of Hawaiian bigeye weight frequency distribution (from figures 5-11)

Month and year	Weight (pounds)			Month and year	Weight (pounds)		
1947				1950 (cont'd.)			
November	40	195	-	December	100	180	-
December	90	140	210	1951			
1948				January	100	175	-
January	40	200	-	February	105	170	-
February	145	195	-	March	110	165	-
March	145	-	-	April	125	165	-
April	145	185	-	May	120	165	-
May	165	-	-	June	115	175	-
June	200	-	-	July	160	-	-
July	-	-	-	August	120	175	-
August	-	-	-	September	85	140	180
September	-	-	-	October	80	140	-
October	-	-	-	November	90	145	195
November	115	170	-	December	95	155	-
December	100	155	-	1952			
1949				January	95	150	-
January	-	-	-	February	70	100	145
February	105	170	-	March	80	145	-
March	110	-	-	April	155	-	-
April	125	180	-	May	155	-	-
May	140	-	-	June	185	-	-
June	-	-	-	July	175	-	-
July	-	-	-	August	170	-	-
August	-	-	-	September	120	180	-
September	145	-	-	October	120	185	-
October	160	-	-	November	115	185	-
November	145	-	-	December	120	185	-
December	145	-	-	1953			
1950				January	115	-	-
January	85	145	-	February	120	165	-
February	85	140	-	March	120	165	-
March	80	145	-	April	130	175	-
April	150	-	-	May	135	185	-
May	145	-	-	June	145	195	-
June	155	-	-	July	160	-	-
July	110	165	-	August	165	-	-
August	165	-	-	September	165	-	-
September	100	160	-	October	165	-	-
October	90	175	-	November	170	-	-
November	95	175	-	December	80	165	-

Table 2.--Time and position of observed modal mid-points of Hawaiian bigeye weight frequency distribution (from figs. 5-11)(cont'd)

Month and year	Weight (pounds)			Month and year	Weight (pounds)		
1954							
January	105	165	-	July	-	-	-
February	100	165	-	August	-	-	-
March	110	175	-	September	-	-	-
April	120	180	-	October	145	-	-
May	170	-	-	November	160	190	-
June	175	-	-	December	155	210	-

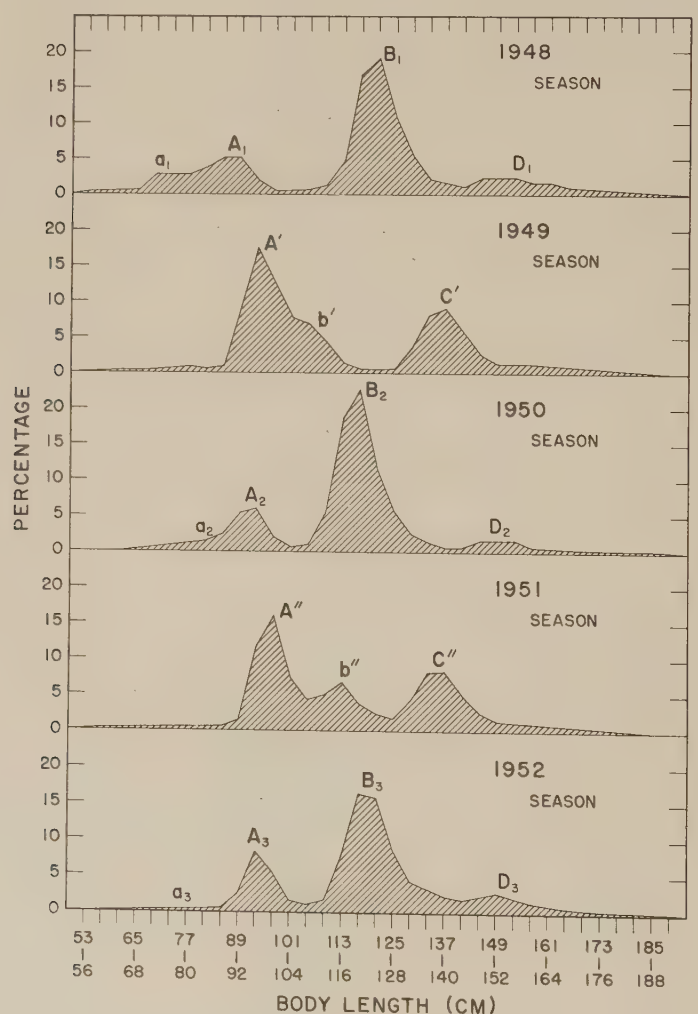

Figure 14.--Bigeye length frequencies by seasons (October-March) for the years 1948-1952. Samples drawn from landings of Japanese commercial vessels operating north of 26°N. between 130°E. and 165°W. longitude. (From Kamimura and Honma (1953))

Table 3.--Modal mid-points and modal ranges from Japanese North Pacific bigeye size frequency distributions

Fishing season	Modal ranges		Modal mid-points	
	From Kamimura and Honma (1953)	Equivalent weight*	From Nakamura et al. (1953)	Equivalent weight*
	centimeters	pounds	centimeters	pounds
948 season	69-80	16-25	73-76[1/]	19-21
December 1948-	81-96	25-42	85-88	29.4-32.5
March 1949	113-132	68-107	121-124	82.6-88.8
	145-164	140-201	149-152	152-161
949 season	89-100	34-47	93-96	38.2-41.9
October 1949-	101-116	49-73	105-108[1/]	54.5-59.1
March 1950	132-148	107-149	137-140	119-127
			Located by Iversen	
950 season	85-100	29-47	92-93	37-38.2
October 1950-	109-128	61-97	117-120	79.4-80.6
March 1951	141-164	129-201	152-153	161-164
951 season	89-104	34-53	97-100	43.2-47.3
October 1951-	105-124	54-89	113-116	67.7-73.0
March 1952	129-152	100-161	136-137	116-119
952 season	89-104	34-53	93-96	38.2-41.9
October 1952-	113-136	68-116	120-121	80.6-82.6
March 1953	141-160	129-187	149-152	152-161

*All equivalent weights are estimated from the formula

Log weight (pounds) = -7.1167 + 2.9304 log total length (millimeters)

1/ Obscure

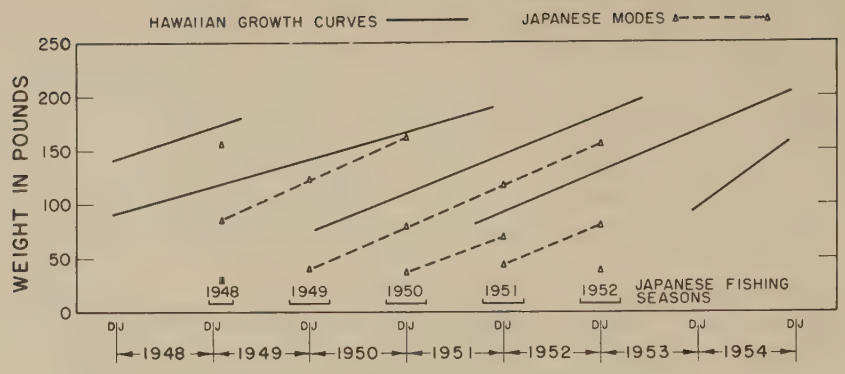

Figure 15.--Comparison of Hawaiian and Japanese bigeye tuna "growth lines" using data from the Japanese North Pacific fishery taken from Kamimura and Honma (1953) and Nakamura et al. (1953).

Nakamura et al. (1953) propose and Kamimura and Honma (1953) discuss at length three hypotheses to explain the "biennial frequency" which they observe in the Japanese North Pacific fishery. These hypotheses are:

"i. Difference in annual propagation;
ii. Difference in annual growth rate;
iii. Difference in annual course of migration."

Kamimura and Honma are unable to decide which hypothesis best fits this phenomenon. They feel that perhaps that of differences in annual propagation (i) is the most reliable and that an annual migratory pattern (iii) may be accepted as a reasonable hypothesis "provided that the fish should take the same migratory route every two years."

Unfortunately even with the added knowledge that this cycle occurs in the Hawaiian fishery there is still insufficient information on the biology of the species to permit a definitive explanation. Some sort of a migratory pattern would seem to best satisfy the relationship of the sizes of bigeye in the two areas. There is considerable circumstantial evidence to indicate that this species may be moving about over a vast expanse of the Pacific. Spawning apparently takes place only over a large area near the Equator, from about 150°E. to 140°W. longitude, and mature or nearly mature females are found there at all times of the year (Kikawa 1953, Yuen 1955). Neither of these authors could find evidence of a spawning area farther to the north. If the

equatorial region is the only area of spawning, those groups of fish from Hawaii and the Japanese North Pacific fishery would have to make an extensive migration to reach this area. Evidence from commercial fishing operations in the western Pacific indicates that there is migration in a north-south direction (Nakamura 1949, Honma and Kamimura 1955).

Further evidence for extensive migration of Pacific bigeye can be seen in modes resulting from measurements of fish at the Equator. Murphy and Otsu (1954) give length frequencies for bigeye measured during the Japanese mothership expeditions west of 180° longitude. These have been plotted using their 5-cm. groups in figure 16. The distributions, which cover June 1950 through October 1951, show that throughout the year a mode is present at about 130-135 cm. (102-114 pounds) that does not appear to progress. During September and October of 1951 a lesser mode appears at about 92-97 cm. (37-43 pounds) that is not present in the other samples. The lack of modal progression with time indicates a constant movement of bigeye into and out of the depths sampled by the longline gear or into and out of the geographic area fished. The occurrence of modes during September and October of 1951 that are not present in the other distributions is also an indication of the migration of a size group into the sampling area.

Additional evidence of migration is found in the Japanese North Pacific fishery, where there is an increase in abundance of the larger size groups with an accompanying decrease in the smaller size groups as one goes from west to east (Nakamura et al. 1953). Since it seems safe to assume that the species grows, the difference in size with area indicates that there are regular and perhaps complex migrations. In figure 15 it can be seen that the Japanese catches have smaller modes (30-40 pounds) than can be found in the Hawaiian catches (the smallest in the Hawaiian data are usually about 80-90 pounds). However, it is also interesting to note that these very small modes appear to be present each year rather than biennially, and that the large modes that occur at about 180-200 pounds in the Hawaiian fishery are not seen in the Japanese fishery.

By way of review, the modal groups of bigeye tuna in the several areas (fisheries) present several puzzling problems. Near the Equator, where ripe fish are taken, there is no progression of modes. In the more northern areas, where spawning has not been noted, the modes progress with time, but there is a curious alternation of modes between years when considering a single area. Considering two well

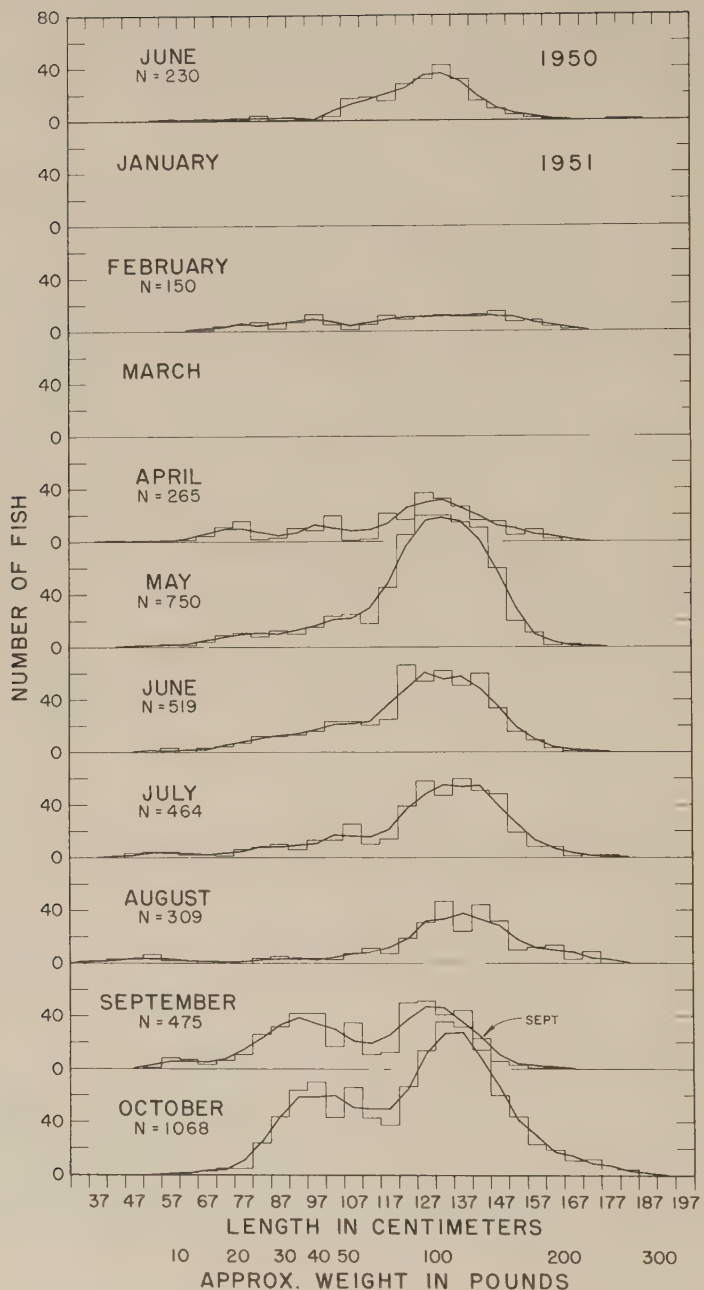

Figure 16.--Length frequencies of bigeye tuna measured during the Japanese mothership expeditions, 140° - 179° E. longitude.

separated fisheries (Hawaiian and Japanese), there is also complementary alternation of modes for a given year. Finally, it appears that once a dominant modal group enters a fishery (e.g. Hawaiian) it may be followed in that fishery for several years. Taken as a whole, these phenomena suggest that the bigeye undertake poorly understood, recurrent, and probably complex migrations.

GROWTH

Incomplete knowledge of some aspects of the life history of bigeye tuna results in a lack of understanding of the usual behavior of the dominant modes in the western and central Pacific. Hence any interpretation of the modes as year groups and interpretation of the movement of those modes as growth must be very tentative.

It is readily apparent from the weight frequency curves covering the period November 1947 through December 1954 in the Hawaiian fishery that clear-cut modal progression is displayed by bigeye tuna (figs. 4-11, table 2). Figure 13, which shows these dominant modes fitted with straight lines, indicates the apparent rate of growth. Table 4 lists the average annual weight increase of these groups as determined from the "growth lines." Assuming that the progression of the modes represents growth, these size groups increase as much as 40-50 pounds in one calendar year. Judging from the slope of the growth curves (fig. 13) and the maximum sizes attained by Hawaiian bigeye, about 6 or 7 years would seem to be a fair estimate of the life span of the species in Hawaii.

However, in the equatorial region the description of growth by the modal progression method is not feasible, since it appears that dominant modes in the size distribution do not progress.

Table 4.--Estimated increase in weights of modes from Hawaiian bigeye tuna distributions

Year	Position of modes (pounds)		Annual increase (pounds)
	January 1	December 31	
	Group A		
1949	110	145	35
1950	145	170	25
1951	170	185	15
	Group B		
1950	80	105	25
1951	105	145	50
1952	145	185	40
	Group C		
1952	90	120	30
1953	120	170	50
1954	170	195	25

SUMMARY

1. A difference in size between the sexes is exhibited by bigeye tuna in samples from the western Pacific and the Hawaiian Islands. The modes of the male size distributions are about 14 cm. or 30 pounds larger than those in female size distributions.

2. Dominant modal groups do not occur in the Hawaiian commercial catch every year, but rather exhibit a cycle that appears to have a period of about 2 years, apparently the complement of the cycle in the Japanese North Pacific fishery.

3. Homologous modes that appear during alternate years in the Hawaiian fishery are not identical in size; rather they increase slightly in size with each recurrence.

4. Approximately similar growth rates and the presence of approximately 2-year cycles of dominant size groups in the catches of both the Hawaiian fishery and the Japanese North Pacific fishery suggest there is a relationship between the bigeye tuna of the two areas.

5. A plot of bigeye weight frequencies by months from the Honolulu market for the period November 1947 through December 1954 reveals modes that progress consistently from smaller to larger sizes.

6. A provisional growth curve plotted by connecting modes found in these size distributions indicates that Hawaiian bigeye may gain as much as 50 pounds in 1 year and may live about 6 or 7 years.

7. In the vicinity of the Equator bigeye modes do not progress with time.

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APPENDIX

Table 5.--Weight frequencies of Hawaiian bigeye, Honolulu market, May-August 1951

Class intervals	Male	Female
lbs.		
50-59	-	1
60-69	1	-
70-79	-	1
80-89	-	1
90-99	-	3
100-109	2	2
110-119	9	10
120-129	8	8
130-139	9	3
140-149	8	-
150-159	9	8
160-169	17	15
170-179	13	11
180-189	13	13
190-199	15	6
200-209	9	8
210-219	9	7
220-229	10	4
230-239	7	1
240-249	8	-
250-259	1	1
260-269	2	-
270-279	1	-
280-289	1	-
290-299	1	-
Total	153	103

Table 6.--Length frequencies of equatorial bigeye by sexes, 5th Japanese mothership expedition March 29-May 28, 1951

Class intervals	Males	Females	Class intervals	Males	Females
cm.			cm.		
50-51	-	2	110-111	1	4
52-53	-	-	112-113	4	9
54-55	-	-	114-115	3	7
56-57	-	1	116-117	10	12
58-59	1	-	118-119	17	9
60-61	-	-	120-121	21	21
62-63	-	3	122-123	33	19
64-65	-	1	124-125	29	15
66-67	1	1	126-127	24	20
68-69	1	2	128-129	30	18
70-71	2	5	130-131	34	19
72-73	1	6	132-133	34	20
74-75	-	11	134-135	28	16
76-77	4	3	136-137	41	7
78-79	5	2	138-139	34	10
80-81	1	3	140-141	30	8
82-83	3	3	142-143	49	1
84-85	2	4	144-145	34	7
86-87	4	3	146-147	36	3
88-89	2	4	148-149	19	-
90-91	4	1	150-151	14	1
92-93	3	5	152-153	7	2
94-95	6	4	154-155	10	1
96-97	4	4	156-157	1	1
98-99	4	5	158-159	5	1
100-101	4	1	160-161	3	-
102-103	6	4	162-163	3	-
104-105	11	5	164-165	2	-
106-107	6	3	166-167	3	-
108-109	11	1			
Total				645	318

Table 7.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1947

Class intervals	Nov.	Dec.
lbs.		
30-39	1	1
40-49	1	5
50-59	-	-
60-69	-	4
70-79	4	6
80-89	2	12
90-99	2	14
100-109	7	8
110-119	15	20
120-129	16	39
130-139	25	56
140-149	21	58
150-159	22	41
160-169	21	18
170-179	24	26
180-189	21	29
190-199	34	32
200-209	18	47
210-219	24	42
220-229	16	34
230-239	10	23
240-249	8	23
250-259	11	12
260-269	6	8
270-279	3	1
280-289	6	4
290-299	4	1
300-309	-	3
340-349	1	-
Total	323	567

Table 8.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1948

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
20-29	-	-	-	1	-	-	-	-	-	1	-	3
30-39	-	-	-	-	-	-	-	-	-	1	1	3
40-49	-	3	1	1	-	-	-	-	3	-	1	4
50-59	-	3	1	3	-	-	-	2	-	1	1	3
60-69	3	-	1	-	-	1	-	-	2	3	5	12
70-79	2	12	3	1	-	1	-	1	6	4	7	15
80-89	5	10	8	3	-	-	-	2	4	5	14	20
90-99	10	23	7	12	3	4	1	1	11	9	22	46
100-109	2	11	10	12	3	3	2	2	11	9	19	57
110-119	3	18	7	16	7	2	6	-	6	7	15	27
120-129	12	40	20	34	7	3	2	3	6	15	20	19
130-139	23	72	43	54	16	3	2	4	5	15	24	31
140-149	11	81	48	72	24	2	4	3	9	14	17	34
150-159	15	61	36	55	21	12	7	5	6	21	18	39
160-169	12	47	29	26	17	11	5	5	8	14	26	35
170-179	6	26	26	28	16	12	3	2	7	12	22	30
180-189	8	37	27	26	21	15	6	2	6	12	16	21
190-199	13	21	19	35	16	20	8	2	6	7	12	12
200-209	11	34	21	15	22	18	5	2	3	12	9	12
210-219	8	22	14	13	7	11	3	2	4	5	3	10
220-229	12	16	14	5	14	11	3	2	4	6	12	8
230-239	3	9	8	6	6	7	3	1	1	5	8	5
240-249	-	6	3	3	5	3	3	1	1	5	6	7
250-259	2	2	3	4	2	3	3	1	1	4	7	2
260-269	1	4	-	1	1	1	-	-	3	-	3	2
270-279	1	3	3	3	-	1	-	-	-	2	2	3
280-289	2	1	1	1	-	-	-	-	-	-	1	1
290-299	2	4	3	-	-	-	1	-	-	-	-	2
300-309	-	-	-	-	-	-	-	-	1	1	-	-
310-319	-	-	1	-	-	-	-	-	-	-	-	-
320-329	-	1	-	-	-	-	-	-	-	-	-	1
330-339	-	-	-	-	-	-	-	-	-	1	-	-
Total	167	567	357	430	208	144	67	43	114	191	291	464

Table 9.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1949

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
10-19	-	-	-	-	-	-	-	-	-	-	-	2
20-29	-	1	1	-	1	-	-	-	-	1	-	-
30-39	-	1	1	1	1	-	-	-	-	2	6	9
40-49	-	3	3	-	1	-	-	-	-	2	9	24
50-59	-	2	4	-	-	1	-	-	-	1	4	18
60-69	-	3	1	-	-	-	-	1	2	8	5	20
70-79	-	7	2	2	2	-	-	1	-	11	10	18
80-89	-	9	4	2	5	1	-	-	-	3	7	21
90-99	6	24	43	12	12	1	-	-	2	3	3	21
100-109	10	47	47	27	34	7	3	1	1	3	11	12
110-119	5	29	50	28	31	10	6	6	7	9	19	36
120-129	6	15	36	33	37	16	3	8	10	13	44	97
130-139	5	19	28	21	38	16	4	6	11	24	82	202
140-149	8	14	30	25	33	13	8	5	20	25	81	205
150-159	16	19	28	16	37	10	5	2	10	27	74	166
160-169	6	25	33	22	36	9	5	2	11	24	52	133
170-179	9	29	18	35	40	12	5	4	9	31	54	106
180-189	4	22	26	31	30	16	3	4	3	27	48	121
190-199	7	12	26	23	18	8	2	3	7	18	51	74
200-209	3	18	10	18	23	12	6	3	4	19	37	67
210-219	8	11	8	13	11	12	6	7	6	16	42	74
220-229	15	6	7	7	11	9	11	4	7	18	27	49
230-239	4	13	2	5	3	7	6	7	7	9	23	30
240-249	4	5	2	4	3	6	2	3	2	9	12	18
250-259	4	3	3	1	2	4	4	1	1	3	9	15
260-269	3	3	1	-	2	2	2	3	-	4	6	15
270-279	1	3	-	-	1	-	-	4	2	3	9	7
280-289	1	-	-	-	-	-	-	-	1	1	3	3
290-299	-	-	-	-	-	-	-	1	1	-	3	-
300-309	-	-	-	-	-	-	-	-	1	1	3	1
310-319	-	-	-	-	-	-	-	-	1	-	-	1
320-329	-	1	-	-	-	-	-	-	-	1	1	1
330-339	-	-	-	-	-	-	-	-	-	1	-	1
340-349	-	-	-	-	-	-	-	-	-	-	-	-
350-359	-	-	1	-	-	-	-	-	-	-	-	-
Total	125	344	415	326	412	172	81	76	126	317	735	1567

Table 10.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1950

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
0-9	-	-	-	-	-	1	-	-	-	-	-	-
10-19	-	-	-	1	3	8	9	14	-	1	-	1
20-29	-	2	-	1	-	4	4	15	-	-	4	2
30-39	1	3	-	9	7	4	6	2	4	7	9	8
40-49	4	5	2	2	5	-	4	3	-	3	7	10
50-59	3	7	8	9	2	2	3	1	1	4	5	11
60-69	5	13	10	16	7	4	9	3	5	18	15	9
70-79	10	21	18	18	23	10	7	6	9	37	27	38
80-89	13	43	10	14	25	22	10	14	19	38	62	79
90-99	7	24	16	34	25	16	16	13	12	40	71	130
100-109	6	12	8	33	41	19	21	9	19	27	58	130
110-119	14	26	20	26	38	23	22	5	16	28	49	78
120-129	26	66	38	71	86	51	12	15	11	26	37	66
130-139	49	108	77	113	157	77	38	12	12	19	42	76
140-149	68	139	80	140	200	97	51	27	20	29	29	56
150-159	42	72	59	123	148	102	88	42	29	58	53	90
160-169	32	61	45	99	126	100	75	56	33	57	78	136
170-179	30	50	38	56	108	85	65	51	22	72	100	176
180-189	38	38	42	47	75	83	72	27	12	61	81	172
190-199	24	35	31	60	79	84	46	28	13	40	69	128
200-209	13	41	23	46	61	62	44	31	17	36	45	109
210-219	12	25	15	41	53	54	30	13	2	25	41	62
220-229	7	27	11	29	35	42	14	19	7	22	35	58
230-239	10	22	6	21	19	24	25	13	7	12	21	52
240-249	8	8	5	10	21	10	5	9	5	11	15	30
250-259	4	5	6	10	9	8	9	7	2	5	13	19
260-269	4	8	4	3	4	3	7	1	-	7	7	18
270-279	-	3	1	2	1	5	5	3	1	6	6	13
280-289	1	1	1	1	1	1	3	3	2	2	2	7
290-299	1	-	1	-	-	-	-	-	-	1	3	6
300-309	-	-	-	-	-	-	1	-	-	3	4	1
310-319	-	-	1	-	-	-	-	-	-	2	1	3
320-329	-	-	-	-	-	-	-	-	-	1	1	2
330-339	-	-	-	-	-	-	-	1	-	-	-	-
Total	432	865	576	1035	1359	1001	701	443	280	698	990	1776

Table 11.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1951

Class intervals	Month											
lbs.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
20-29	-	-	1	-	-	-	-	-	-	1	-	-
30-39	2	-	2	-	-	1	-	-	-	2	2	5
40-49	3	1	5	1	2	1	1	1	-	8	3	8
50-59	1	-	10	12	3	1	3	1	1	6	2	12
60-69	3	3	2	3	2	5	3	6	12	10	3	14
70-79	2	8	5	3	1	-	2	2	18	40	15	15
80-89	23	32	26	12	14	-	-	3	2	34	17	33
90-99	43	65	37	30	17	14	1	2	9	17	6	21
100-109	37	40	71	57	53	24	10	11	14	20	8	15
110-119	22	48	63	82	75	40	25	24	15	34	20	31
120-129	17	18	43	86	51	26	29	19	36	80	43	52
130-139	17	13	44	62	58	21	37	19	47	113	82	112
140-149	21	19	56	79	59	21	25	8	44	103	130	221
150-159	24	32	72	103	84	31	34	18	31	89	110	256
160-169	40	55	59	91	93	43	25	16	23	51	63	186
170-179	33	39	80	108	63	34	28	28	18	63	51	116
180-189	29	37	47	78	78	38	40	22	32	49	63	88
190-199	36	27	28	44	61	38	27	17	20	45	60	97
200-209	13	31	17	33	45	25	27	11	18	45	69	90
210-219	14	12	15	22	34	23	19	5	13	31	48	83
220-229	15	15	7	12	24	11	14	7	12	22	43	45
230-239	9	9	5	6	21	11	10	4	4	19	32	40
240-249	7	14	2	7	12	12	14	2	4	11	23	22
250-259	4	6	3	2	3	2	3	1	1	8	20	23
260-269	2	-	1	4	4	3	2	1	1	4	9	10
270-279	1	-	1	2	1	-	1	1	-	6	5	8
280-289	1	1	2	-	-	1	1	2	1	3	3	7
290-299	-	2	-	-	1	1	1	-	1	1	1	3
300-309	-	-	-	-	-	-	-	-	-	1	1	2
310-319	-	-	-	-	-	-	-	-	-	-	-	1
Total	419	527	704	939	859	427	382	231	377	916	932	1616

Table 12.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1952

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
20-29	-	-	1	-	-	-	-	-	-	-	-	-
30-39	1	2	-	1	-	-	-	-	-	1	3	3
40-49	4	11	4	2	1	-	-	-	-	-	1	5
50-59	21	33	14	1	1	-	-	-	-	4	2	4
60-69	15	17	15	8	1	-	-	1	1	1	1	9
70-79	9	15	14	3	4	1	1	1	4	7	4	9
80-89	34	25	11	4	3	-	1	2	11	27	18	25
90-99	46	34	14	9	16	2	4	1	13	29	44	75
100-109	29	34	15	12	28	9	10	7	14	28	54	128
110-119	21	32	18	33	39	10	14	8	11	37	66	134
120-129	34	55	52	56	35	14	10	10	14	43	60	145
130-139	67	119	89	105	71	14	5	9	15	22	42	132
140-149	99	163	136	166	97	17	21	20	16	40	34	70
150-159	93	124	131	207	145	26	11	23	22	25	44	92
160-169	68	75	73	182	99	24	19	26	22	52	51	104
170-179	34	62	68	129	112	26	26	35	52	66	67	115
180-189	28	68	62	76	70	24	21	25	34	75	74	131
190-199	32	58	58	76	65	18	21	16	28	68	76	123
200-209	22	64	47	83	66	20	13	14	25	57	54	82
210-219	22	33	33	44	50	23	10	6	15	44	48	50
220-229	15	23	26	43	34	17	5	3	9	40	28	39
230-239	15	14	16	16	31	6	6	5	4	26	24	26
240-249	10	13	12	8	14	5	2	6	8	25	15	23
250-259	3	6	8	7	3	3	2	2	3	16	23	13
260-269	2	9	6	6	6	2	-	-	-	9	11	17
270-279	1	7	3	2	2	2	-	1	-	6	6	3
280-289	1	3	1	1	1	2	-	2	-	2	6	3
290-299	3	-	1	2	1	-	-	-	2	-	4	1
300-309	1	3	-	2	-	-	-	-	-	1	2	-
310-319	-	-	-	-	-	-	-	-	-	-	4	1
320-329	-	-	-	-	-	-	-	-	-	-	-	-
330-339	-	-	-	-	-	-	-	-	-	-	-	-
340-349	-	-	-	-	-	-	-	-	-	-	1	-
350-359	-	-	-	-	-	-	-	-	-	-	1	-
360-369	-	-	-	-	-	-	-	1	-	-	-	-
380-389	-	-	-	-	-	-	-	-	1	-	-	-
Total	730	1102	928	1284	995	265	202	224	324	751	868	1562

Table 13.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1953

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
10-19	2	-	-	-	-	-	-	-	1	-	-	-
20-29	1	-	2	1	-	-	-	-	-	4	-	-
30-39	1	4	2	-	-	-	-	-	3	9	-	3
40-49	1	4	8	1	-	-	-	-	8	13	-	5
50-59	3	3	2	6	-	-	-	-	-	7	1	8
60-69	-	1	-	-	-	-	-	2	2	3	1	7
70-79	-	1	4	1	1	1	1	-	-	6	4	20
80-89	5	17	15	3	-	-	-	-	3	3	7	21
90-99	11	49	40	11	3	-	1	1	-	-	-	5
100-109	27	65	77	23	14	1	6	4	-	1	2	6
110-119	41	111	81	51	34	11	10	6	7	7	5	12
120-129	31	118	107	72	89	22	22	10	3	14	14	17
130-139	15	63	73	73	85	38	24	5	14	23	17	34
140-149	14	76	54	55	70	38	29	18	16	29	28	57
150-159	8	62	57	42	52	29	38	20	33	49	61	99
160-169	15	57	52	49	53	22	32	17	35	45	82	143
170-179	11	78	54	46	68	36	24	13	30	46	80	118
180-189	10	62	52	51	71	31	34	16	18	26	56	78
190-199	14	54	36	41	62	41	28	9	24	21	28	58
200-209	5	50	25	35	61	42	26	11	12	19	34	33
210-219	6	25	17	15	53	22	17	11	5	21	31	21
220-229	7	14	20	17	36	21	11	4	4	12	22	19
230-239	2	8	7	11	14	8	9	3	1	13	16	16
240-249	5	12	4	5	11	5	7	3	5	7	13	11
250-259	1	5	2	1	7	3	1	1	-	5	4	7
260-269	2	6	3	1	4	-	3	-	1	4	4	4
270-279	1	4	-	-	3	2	1	-	1	4	5	3
280-289	-	-	2	-	2	-	-	3	-	2	2	1
290-299	1	2	-	-	-	-	-	-	-	-	5	-
300-309	-	3	-	-	-	-	-	-	-	-	-	-
310-319	-	-	-	-	-	-	-	-	-	1	-	-
320-329	-	-	-	-	-	-	-	-	-	-	1	-
340-349	-	1	-	-	-	-	-	-	-	-	-	-
Total	240	955	796	611	793	373	324	157	226	394	523	806

Table 14.--Weight frequencies of Hawaiian bigeye, sexes combined, Honolulu market, 1954

Class intervals	Month											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
lbs.												
20-29	-	-	-	-	-	-	-	-	1	-	-	-
30-39	1	-	-	1	-	-	-	-	-	4	2	-
40-49	3	3	-	1	-	-	-	-	-	3	11	11
50-59	-	3	1	3	-	-	-	-	-	2	15	16
60-69	1	6	2	4	-	-	-	-	-	4	5	4
70-79	8	16	-	-	2	-	-	-	5	10	8	7
80-89	10	15	9	2	-	-	-	1	2	17	17	12
90-99	11	21	9	7	5	1	-	-	-	9	25	28
100-109	8	21	13	16	5	3	-	-	6	8	16	34
110-119	3	9	12	28	9	3	-	4	8	15	14	33
120-129	6	11	9	19	6	3	-	2	9	21	31	37
130-139	12	18	5	12	18	3	-	1	8	23	27	49
140-149	15	30	17	35	18	8	1	-	6	26	29	61
150-159	30	59	30	64	36	4	1	1	8	12	30	66
160-169	37	82	66	79	66	16	4	3	9	23	31	52
170-179	29	60	43	132	59	18	3	4	7	25	29	52
180-189	20	52	47	111	41	17	6	4	10	24	36	45
190-199	10	37	30	74	39	10	3	1	12	28	33	53
200-209	12	35	21	56	24	12	6	3	7	22	40	84
210-219	5	27	14	46	13	2	4	4	12	26	33	67
220-229	7	11	22	32	17	2	-	2	2	13	33	39
230-239	6	12	9	19	4	1	-	6	2	15	17	21
240-249	3	8	6	14	5	6	-	1	4	7	16	13
250-259	4	3	3	7	4	1	1	1	3	4	8	14
260-269	-	3	4	8	-	1	2	-	2	7	3	2
270-279	1	4	2	3	1	2	-	-	1	-	-	5
280-289	-	2	-	-	-	-	-	-	-	5	4	1
290-299	-	1	-	-	-	-	-	-	-	-	3	-
300-309	1	-	1	-	-	-	-	-	-	-	-	-
310-319	-	1	-	-	-	-	-	-	-	1	1	-
320-329	-	-	-	-	-	-	-	-	-	1	-	-
330-339	-	1	-	-	-	-	-	-	-	-	-	-
Total	243	551	375	773	372	113	31	38	124	355	517	806

Annotated List of Birds Observed on Christmas Island, October to December, 1953

JOSEPH E. KING

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Annotated List of Birds Observed on Christmas Island, October to December 1953

Joseph E. King[1]

In October 1953, the Pacific Oceanic Fishery Investigations of the U. S. Fish and Wildlife Service landed a small field party (the author and Mr. Richard Shomura) on Christmas Island for the purpose of installing weather instruments and sea thermographs, and to conduct a tuna bait-fish survey of the lagoon. We were on the island from October 23 to December 9, 1953, and although our time was generally occupied with the duties mentioned above, we had many opportunities to observe the interesting bird life of the island. As Christmas and other islands of the Line Island group (Fanning, Washington, and Palmyra) are rarely visited by ornithologists, we thought it worthwhile to report our observations.

The author is indebted to Dr. Frank Richardson for his helpful review of the manuscript.

Christmas Island (Fig. 1), lies in the equatorial Pacific about 1,200 miles south of Hawaii at 2° N. latitude, 157° W. longitude. It is about 35 miles in length, in a northwest–southeast direction, and about 17 miles in width. The island is a large coral atoll with a perimeter of about 105 miles. Enclosed within the outer coast is an area estimated at 382 square miles, of which approximately 250 are land and 107 are lagoon; about 25 square miles are occupied by numerous salt lakes (Wentworth, 1931). The island is generally low, averaging about 10 feet or less in elevation, except along the southern shore of the Bay of Wrecks where there are scattered sand dunes which may reach 40 feet in height.

The rainfall is quite variable but averages 25 to 35 inches a year (Bryan, 1942). Fragmentary records show an annual range from 10 inches to as much as 100 inches. The air temperature varies from a minimum of 68° or 70° F. to a maximum of 106° F. (Wentworth, 1931).

Christophersen (1927) records 24 species of vascular plants as growing naturally on Christmas Island. These include *Tournefortia argentea* trees, clumps of *Scaevola frutescens* and other low shrubs, grasses, and herbs. Although all the coconut palms now seen on the island have been planted, there were a few palm trees present at the time of Captain Cook's visit in 1777. There are now extensive coconut groves in the northwestern, northern, southwestern, and southern parts of the island.

The vertebrate fauna of the island consists mainly of the fishes that abound in the lagoon and coastal waters and the abundant bird life that forms the subject of this report. In addition there are lizards, rats, and cats; many of the latter roam in a wild state, and while they may help keep down the rat population, they also without doubt prey on the ground-nesting birds.

Great Britain claims sovereignty over the island and has brought in natives from the Gilbert and Ellice Colony to provide a labor

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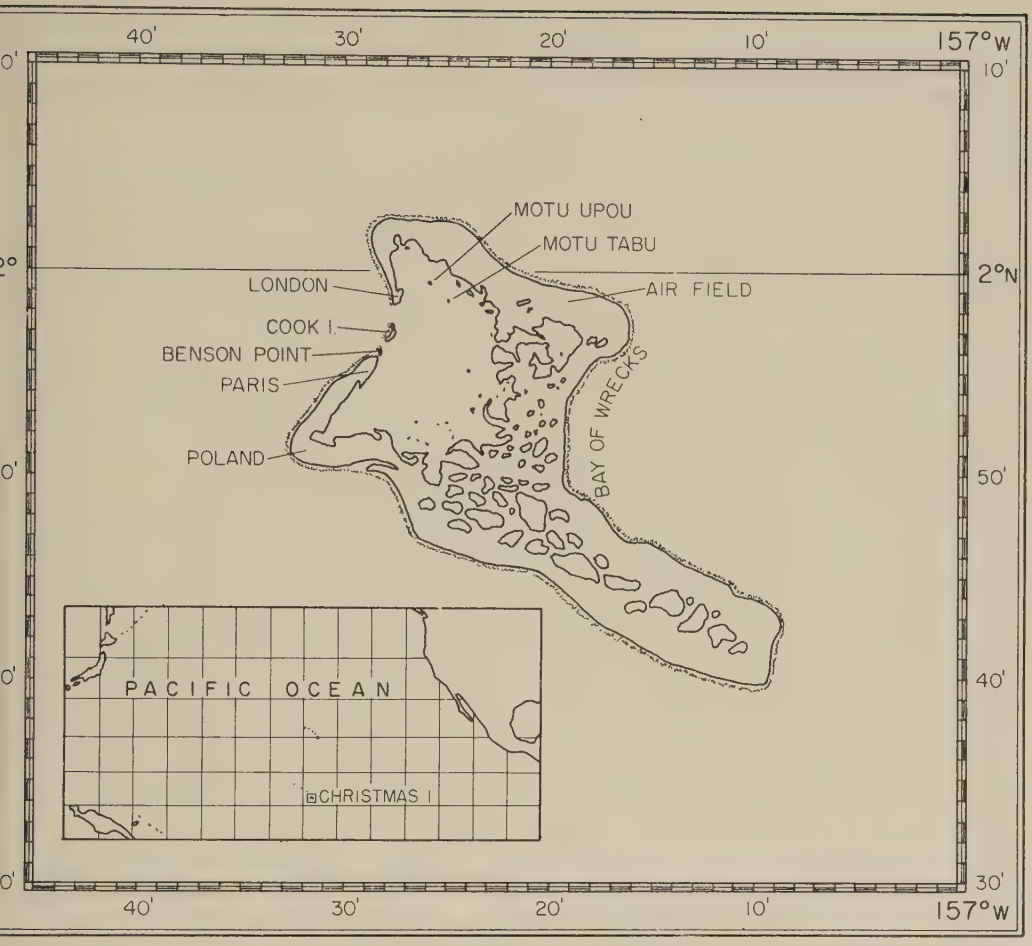

FIG. 1. Christmas Island, showing locations referred to in the text and the island's general position in the central ific (inset). (Drawn with modifications from USN Hydrographic Office Chart No. 1839.)

ce for the plantation. There is no indi- ious population.

A review of the literature describing the fauna of Christmas Island begins with the ount of its discoverer, Captain James Cook. the afternoon of December 24, 1777, Cap- Cook brought his ships the "Resolution" the "Discovery" to anchor off the west e of the island. On the next day—Christ- s Day—he and his men went ashore at k Island (Fig. 1), a small patch of coral sand separated from the main island. He es (Cook, 1784), "As we kept our Christ- here, I call this discovery Christmas Island." The vessels stayed at anchor several days to permit the men to refresh themselves and to observe an eclipse of the sun. Cook reports that there were no traces of human beings having been there before and that the number of coconut trees did not exceed 30. He had the following to say about the animal life *ibid.*, p. 188–189):

> Under the low trees above-mentioned, sat infinite numbers of a new species of tern, or egg-bird. These are black above, and white below, and with a white arch in the forehead [apparently sooty terns]; and are rather larger than the common noddy. Most of them had lately hatched their young, which lay under old ones, upon the bare ground. The rest had eggs; of which they only lay one, larger than that of a pigeon,

bluish and speckled with black. There was also a good many common boobies; a sort that are almost like a gannet [most likely the blue-faced booby]; and a sooty or chocolate-coloured one, with a white belly [the brown booby]. To this list we must add men-of-war birds; tropic-birds; curlews; sand-pipers; a small land-bird like a hedge sparrow [the kokikokiko, as named by the Gilbertese]; land crabs; small lizards; and rats.

The whaling ship "Tuscan" stopped at Christmas Island in May, 1835. Bennett (1840) gives an interesting account of the visit and states that, "Here and there among the low thicket scrubs are vast rookeries of aquatic birds, whose clamour is deafening." He mentions "sooty terns," "red-tailed tropic birds," "pure snow white petrels," probably white terns, "boobies," blue-faced boobies from the description, other "terns," probably noddies, "frigate birds," "petrels," "curlews," bristle-thighed curlews, "quail," probably golden plover, and a "sparrow-like land bird," the kokikokiko.

Streets (1877) visited Christmas Island in the vessel "Portsmouth" during the course of the United States North Pacific Surveying Expedition of 1873–75. Nine species of birds were reported and a collection was made. Father Emmanuel Rougier (1914), who at one time held a lease on the island, has published one of the most complete descriptions of Christmas Island, including its flora and fauna. He lists the following birds: frigate bird, sooty tern, grey-backed tern, Necker Island tern, Hawaiian tern, noddy tern, white tern, Christmas Island shearwater, red-tailed tropic bird, blue-faced booby, red-footed booby, and the kokikokiko (a small land bird), a total of 12 species. Kirby (1925) reports 11 species of sea and shore birds (including the bristle-thighed curlew, wandering tattler, and golden plover) plus several kinds of migratory ducks (which he does not name) as occurring on the island. He states that birds have been greatly reduced in number (prior to 1925) throughout the Line Islands as a result of land clearing and other disturbances by man. In 1921 the Whitney Expedition of the American Museum of Natural History carried on an investigation of the birds of Christmas Island. Specimens of the kokikokiko, *Conopoderas aequinoctialis aequinoctialis* (Latham), collected at this time have been described by Murphy and Mathews (1929).

The following is a list, with a few life-history notes, of the birds seen by the author during his stay on Christmas Island from October 23 to December 9, 1953. In general, Peters (1931, 1934) has been followed in respect to scientific names.

Puffinus nativitatus Streets, Christmas Shearwater. Abundant. Observed nesting with eggs and young on the islets of Motu Tabu and Motu Upou within the lagoon. Nests were in shallow tunnels or depressions over-hung with grass or low shrubs.

Pterodroma alba (Gmelin), Phoenix Petrel. Abundant. Observed nesting with eggs (Fig. 2*d*) and young on the islets of Motu Tabu and Motu Upou. This petrel could be seen throughout the day, flying low over the land and lagoon, and was more commonly seen over land than was the Christmas shearwater. Nesting habits were the same as for that species.

Nesofregetta albigularis (Finsch), White-throated Storm Petrel. Uncommon. Observed near shore (October 22) when we were approaching the island from the north, and seen on several occasions flying over the lagoon and outer beach. One bird of this species was found nesting, with one egg, on the islet of Motu Tabu. The egg was in a shallow depression over-hung by a thick cover of grass.

Phaethon rubricauda melanorhynchos Gmelin, Red-tailed Tropic Bird. Abundant. Observed nesting with eggs and young (Fig. 2*c*) throughout the island. Egg usually was placed under the low shrubs of *Scaevola* or the larger *Tournefortia*.

Sula sula rubripes Gould, Red-footed Booby. Abundant and generally distributed throughout the island. Nests with eggs and young (Fig. 2*e*) were observed principally in *Tournefortia* trees.

G. 2. Some of the birds of Christmas Island; photographed by the author. *a*, Young white tern on the remains nest of the white-capped noddy; *b*, young white-capped noddy on the nest; *c*, red-tailed tropic bird with g; *d*, Phoenix petrel with egg; *e*, red-footed booby with young; *f*, blue-faced booby with eggs.

Sula dactylatra personata Gould, Blue-faced Booby. Common but considerably less so than *S. s. rubripes*. Eggs and young were observed principally in the less visited areas. The eggs are deposited on the ground in a slight depression with no nesting materials (Fig. 2*f*). A booby of this species was seen setting on two eggs on October 28, one of which hatched on December 8 indicating that the incubation period exceeds 42 days.

Sula leucogaster plotus Forster, Brown Boody. Common in certain areas, such as the Bay of Wrecks and Benson Point. No eggs or young were seen.

Fregata minor palmerstoni Gmelin, Frigate Bird. Abundant, but not observed to be nesting. These birds seemed to make their living primarily at the expense of the boobies, which they would attack by diving from a considerable height and continually torment until the unfortunate booby surrendered its food. Specimens in immature plumage were common.

Sterna fuscata oahuensis Bloxham, Sooty Tern. The most abundant bird on the island. Was present in large numbers in October but appeared in huge congregations in the latter part of November and started to nest in the first week of December. The main nesting areas were located in the northwestern part of the island, between Poland and Paris, on Cook Island, and on parts of the large southeastern peninsula.

Thalasseus bergii cristatus Stephens, Crested Tern. Common; not observed to be nesting. This is the largest tern of the Pacific and not previously reported for Christmas Island.

Anous stolidus pileatus (Scopoli), Common Noddy. Common but found with eggs only on Cook Island during our visit. Eggs were deposited on the ground under *Scaevola* shrubs.

Procelsterna cerulea cerulea (F. D. Bennett), Blue-grey Noddy. Abundant. Observed with eggs and young on Cook Island and Motu Tabu. The eggs were found in areas almost barren of vegetation.

Anous minutus minutus Boie, White-capped Noddy. Common. Was nesting with eggs and young on Cook Island, Motu Tabu and Motu Upou (Fig. 2*b*). The nest was constructed of leaves, twigs, and grass and placed in the *Tournefortia* trees.

Gygis alba candida (Gmelin), White Tern. Abundant. Observed with eggs and young (Fig. 2*a*) on Cook Island, Motu Tabu, and Motu Upou. The egg is deposited on a bare horizontal trunk or limb of the larger shrubs or trees. The eggs are easily dislodged and the writer returned many eggs, which had fallen to the ground, to their former location after flushing the incubating adult bird. These terns were observed returning to their young with what appeared to be four to six small fish lined up in their beaks. This feat has been noted many times and while it is thought that the tongue may assist in the operation, the details of the phenomenon still remain a mystery.

Anas acuta tzitzihoa Vieillot, Pintail Duck. One or two ducks of this species were occasionally sighted in the ponds near the airfield. From the shore of the Bay of Wrecks, on November 18, a flock of about 20 birds thought to be pintails, were seen flying in off the ocean from the northeast.

Pluvialis dominica fulva (Gmelin), Pacific Golden Plover. Abundant. Occurring generally throughout the island even in the streets of the native village. In fact it seemed more abundant in the dry areas with little vegetation than along the beaches and mud flats. During the period of our visit birds were seen in a variety of plumage patterns from the dark-breasted breeding plumage to the light-breasted winter condition.

Numenius tahitiensis (Gmelin), Bristle-thighed Curlew. Common to abundant. Observed in many different habitats on the island, from the dry interior areas to the ocean and lagoon beaches.

Heteroscelus icanus (Gmelin), Wandering Tattler. Probably the most abundant shore

rd on the island, occurring almost every-
here near water.
aria interpres interpres (Linnaeus), Turn-
one. Small flocks of these birds were seen
n three occasions at the ponds near the
rport.
ethia alba Pallos, Sanderling. One bird of
is species was seen near London Village
n the morning of November 7.
us delawarensis Ord, Ring-billed Gull. An
mature specimen of this species was
ghted in the lagoon behind London Vil-
ge on November 15. It was examined at
ose range twice that day and again the
ext two days, but not seen thereafter. This
rd is certainly a rare visitor to the central
cific and the author is not aware of any
evious record of the species for the Line
land group.
poderas aequinoctialis aequinoctialis (Lath-
n), Kokikokiko. Common in the higher
d more dense growths of *Tournefortia*.
ld nests were found but none containing
gs or young. This species is flycatcher-
e in appearance and is the only native
nd bird on the island. These birds stayed
ose to cover and were rarely seen in flight.

though the author was in the field every
during the 7-week stay and covered the
d rather thoroughly several times, except
he long peninsula extending to the south-
it is very probable that the above list
ot complete for the period of our visit.
example, the wedge-tailed shearwater
inus pacificus chlororhynchus Lesson), one
ne most abundant of the Procellariidae
e mid-Pacific, is reported to nest on the
d (Alexander, 1928; Murphy, 1951) but
not seen there during our visit. The gray-
tern (*Sterna lunata* Peale) is supposed to
throughout Oceania (Alexander, 1928)
nas been observed on Christmas Island
gier, 1914). We believe we sighted this
on a few occasions but were not able to
tify it with certainty. The white-tailed
c bird (*Phaethon lepturus dorotheae* Math-
ews) has been observed by the author on Fanning and Washington islands but not on Christmas, and according to Kirby (1925) it does not occur there. The author has also admired the brightly colored parakeets, *Vini kuhlii* (Vigors), on Fanning and Washington islands but did not find them on Christmas and probably they have never become established there (Tristram, 1883). The black-footed albatross (*Diomedea nigripes* Audubon) is common in the temperate and subtropical North Pacific and has been observed by the author as far south as 7° N. latitude (on December 14, 1953). It may occasionally visit the Line Islands area, but as yet we have not encountered it there on any of the several POFI cruises from 1950 to 1954.

Except for the golden plover, tattler, and curlew, there was a general lack of shore birds on the island during the period of our stay. Ducks also were scarce. About the middle of November, Mr. Phil Palmer of Fanning Island, which is about 150 miles northwest of Christmas, reported that a large number of ducks had just arrived on that island during a rainstorm. Apparently none of these birds reached Christmas.

Some information of interest and value was obtained from Latia, the "old man" of the island. He reported that on Christmas Island the sooty terns have two nesting periods: a mid-winter period from December to March, and a mid-summer period from June to August. About equal numbers of birds take part in each nesting. The red-tailed tropic birds nest from June to January and the frigate birds from December to June. There are some shearwaters and petrels nesting throughout the year. The boobies have eggs and young over a good part of the year, particularly during the fall and winter months. Usually a few ducks show up each winter but never in great numbers. Mr. Richard Cooper, British Officer for the Line Islands, reported that the small land bird, called the "kokikokiko" by the Gilbertese, lays its eggs in the summer months.

In summary, 22 species of birds were iden-

tified on Christmas Island during the period October 23–December 9, 1953. Of this number, 11 species were observed with eggs or with eggs and young. The author believes this to be the first report of the occurrence of the crested tern and the ring-billed gull on Christmas Island or for the Line Island area.

ADDENDUM

Since the submission of this manuscript the author has made another visit to Christmas Island, June 5 and 6, 1954. Other duties prevented a thorough survey of the Island, but through the courtesy of British District Officer Percival Roberts, a short trip was made to the islet of Motu Tabu. Species observed nesting with eggs and young were the Christmas shearwater, white-capped noddy, common noddy, white tern, and red-tailed tropic bird. The Phoenix petrel was brooding eggs, but no young were seen. The blue-grey noddy was quite abundant on the islet, but no eggs or young could be found. Sooty terns, crested terns, frigate birds, and red-footed boobies were observed flying over the lagoon. Some of the Gilbertese plantation staff informed us that the sooty terns had not yet started to nest but had already begun to congregate on the main island for their summer nesting season.

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RIATIONS IN ZOOPLANKTON ABUNDANCE IN THE CENTRAL EQUATORIAL PACIFIC, 1950-1952

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RIATIONS IN ZOOPLANKTON ABUNDANCE IN THE CENTRAL EQUATORIAL PACIFIC, 1950-1952

by

J. E. King*

abundance of zooplankton as an index to al fish production is significant to the study high seas fishery resources of the tropical o-tropical regions of the central Pacific being out by the Pacific Oceanic Fishery Investi- (POFI) of the U.S. Fish and Wildlife Ser- In this report we shall review the primary of our zooplankton sampling in the equatorial from our initial year, 1950, through 1952. ta will be examined for variations associated titude, longitude, and season. We shall ut, very briefly, certain relationships which to exist among the hydrographic features of ironment, the zooplankton, and the tunas.

lankton is a basic food of much of the verte- una of the sea. It is directly utilized even large and fast moving fish as the tunas, the f fish presently under study by these Investi- For example, representatives of the follow- ps have been captured in our plankton nets e also been found among the stomach con- maturing and adult yellowfin tuna (Reintjes g, 1953).

sids	brachyuran larvae
hausiids	heteropods
phipods	pteropods
natopod larvae	cephalopods
mps	tunicates
nurid larvae	fish larvae and juveniles

k of the zooplankton, however, reaches the directly through intermediary forage orga- nch as squid, fish, and the larger shrimp.

r plankton sampling in this area has con- rincipally of scattered collections. Some of or oceanographic expeditions, the *Challenger atross* and the *Dana*, while traversing the Pacific, made a few hauls which were largely ve and chiefly of value in systematic and distributional studies. The *Carnegie* visited the central Pacific in 1929 and made quantitative hauls on a generally north-south section crossing the Equator. The resulting data (Graham, 1941) are difficult to compare with our own but do provide evidence on variation in plankton dry weights as related to latitude and the equatorial current system. The work being carried out by POFI is, however, the first comprehensive quantitative survey of zooplankton abundance in the equatorial central Pacific and the first attempt to correlate the physical and chemical environment, zooplankton abundance, and tuna catch.

The Pacific Oceanic Fishery Investigations are under the directorship of Mr. O. E. Sette, who has contributed many of the ideas expressed in this report. Miss Joan Demond[1] and Mr. Thomas S. Hida[2] assisted in making the zooplankton volume determinations on which this report is based. We are indebted to Messrs. Garth I. Murphy[3] and Richard S. Shomura[3] for supplying the yellowfin tuna catch records. The hydrographic data were collected and processed under the supervision of Messrs. Thomas S. Austin[4] and Townsend Cromwell[5]. The author is responsible for combining and averaging the tuna catch records and the inorganic phosphate data for the purpose of comparing them with the zooplankton volumes.

This report is based on 405 collections taken on 10 cruises of the Fish and Wildlife Service vessel *Hugh M. Smith* during the years 1950 to 1952. The time of year of each cruise, the general area visited and the number of collections are listed in Table 1. The area sampled (Fig. 1) extends from 120° W. longitude on the east to 180° longitude on the west, with a range of latitude from 27° N. (on 175°W. longitude, to 14-1/2° S. (on 172°W. longitude). The geographic position for each plankton station and the value of each collection as a count

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or volume of zooplankton have appeared, or will appear, in other publications of the Fish and Wildlife Service (King and Demond, 1953; King and Hida, 1954). Most of the cruises consisted of one or more long series of stations (as illustrated in Fig. 2 for cruise 5) extending in a north-south direction, crossing the Equator and the major equatorial currents.

Cruises 2, 5, 8, 15 and 16 were combined hydrographic and plankton cruises and thus provide information on currents, temperatures, oxygen and inorganic phosphate for comparison with the zooplankton abundance. Cruises 7, 9 and 18 of the *Smith* were primarily tuna fishing expeditions on which some plankton collections were made; cruises 11 and 14 were combination fishing, hydrographic and plankton cruises.

The plankton nets used in making these collections were 1 meter in mouth diameter and about 5 meters in overall length. Front and middle sections of the net were of 30xxx silk grit gauze (apertures 0.65 mm square); the rear section and bag were of 56xxx grit gauze (apertures 0.31 mm square). The 30xxx grit gauze comprised about 97 per cent of the straining surface of the net.

Nets of this mesh size retained the tuna eggs (of about 0.80 mm diameter) and tuna larvae, the capture of which was one object of the study. Almost all phytoplankton passed through the net, and thus a relatively "clean" sample of zooplankton was obtained. A flow meter suspended in the mouth of the net gave an estimate of the amount of water strained on each haul. Thus the results could be expressed in terms of cubic centimeters of zooplankton per unit of water strained.

As we were limited to a single tow at each station, we chose to use, for the greater part, an oblique haul. This method of hauling has been shown by Winsor and Clarke (1940) to be subject to less sampling error and to provide more reliable and consistent results than vertical or horizontal hauls. In making the haul the net was lowered at a slow, uniform speed to a calculated depth of 200 meters (estimated from wire out and angle of stray from the vertical, assuming the towing wire to describe a straight line in the water), and then retrieved at the same slow, uniform speed. Following this practice the oblique tow to 200 metres required about 30 minutes, and approximately equal amounts of time were spent at all depths. The amount of water strained on each haul varied from 1,000 to 1,500 cubic metres.

For cruises 2, 5, 7 and 8, a measured fraction of each sample was counted and the displacement volume was determined (the zooplankton counts are not utilized in this report). For all subseq cruises, the displacement volume of the e sample was measured but no counts were m During the course of the work, refinements in t nique have been introduced which tend to gi more accurate estimate of the amount of plankton—as food—present at each station. tailed descriptions of the methods employe processing the samples are given in recent re (King and Demond, 1953; King and Hida, 195

For purposes of comparison, the zooplan volumes were grouped according to their pos into 5-degree intervals of latitude and 10-de intervals of longitude. The intervals of lati chosen were as follows: 0°00′ to 4°59′, 5 to 9°59′, etc. The few samples occurring at 0 were assigned to the 0°-4°N. group or the 0°-4 group depending upon the direction the sec was being traversed, e. g., if the direction of m ment was to the south, the sample was assigne the southern (0°-4° S.) group. The interval longitude selected were as follows: 120° to inc samples from 115°00′ to 124°59′, 130° to inc samples from 125°00′ to 134°59′, etc.

When the data from all 10 cruises were comb irrespective of longitude and season into 5-de latitudinal groups and graphically portraye in figure 3B, the peak of abundance was foun occur near the Equator in the South Equat Current but displaced slightly to the north and spilling over somewhat into the Countercur The poorest areas within the range of lati sampled were those in the North Equatorial Cur An average of zooplankton volumes, include figure 3B, obtained on four cruises in Haw waters during the years 1951 to 1953 shows Hawaii ranked a little higher than parts of the N Equatorial Current, but considerably lower the equatorial region.

Figure 3B is a composite, however, inclu many cruises occurring at different times of year and with sampling along different longitu from 120° W. to 180°. A more accurate pic may be obtained from Table 2, where the latitud variation is shown for each 10 degrees of longit Table 3 is included to point out differences an four major cruises, with two cruises (2 an occurring during the northern winter season and cruises (5 and 11) occurring in the late nort summer. Through an analysis of variance, and Demond (1953) found no significant differe ($P > 0.05$) between longitudes for both cruis and 8 but highly significant differences ($P <$ between cruises. In general, it appears tha equatorial region produced a larger zooplan crop in the winter of 1950 than in the winte

The summer crops of the two years are equal.

le 4 was constructed for the purpose of ning further the variations with season of the nd with longitude. The sampled area in- portions of both hemispheres and since yet had no evidence as to natural seasons plankton abundance in the tropical Pacific, lendar year was divided into quarters as ted in Table 4. Since latitude is a third le to be taken into account, Table 4 is arranged w variations with longitude and " season " ree latitudinal groups: 4°N-0°, 0°-4°S. N-4° S. These are the latitudes for which ve the most observations and they are also eas of greatest plankton production. The means in the table indicate that longitudes o 120° produced in general the largest es, although our data are not sufficiently te to provide entirely reliable conclusions. 4A, which summarizes the variation with de for all observations between 9° 59′ N. 59′ S. latitude, shows a gradient of increasing nce from west to east, with a levelling-off 140°. Certain of the longitudes were sam- only one period of the year, however, so cture of longitudinal variation may change hat with future sampling.

respect to seasonal variation, the period y—February—March ranked low for most des. July—August—September, almost t exception, marked the period of greatest tion (great significance should probably attributed to the three observations for r — November — December, 4°N.-0° , 160° W. longitude). Perhaps the most feature of the data as portrayed in Figure he absence of the great seasonal variation is so characteristic of plankton abundance er latitudes.

ical seas have been considered less pro- than those of higher latitudes on the s that surface heating in the tropics results able stratification of the sea, thus limiting mixing by convection which would bring ts to the euphotic zone (Delsman, 1939, , 1941; Sverdrup *et al.*, 1942, p. 942). hermal stratification does apparently exist out much of the tropical and sub-tropical It was learned, however, from the last f the *Carnegie* in 1929, that these generally onditions are disrupted at the Equator by ence of the surface waters resulting in up- The latter was considered responsible chment of the surface waters and the pro- duction of much greater concentrations of plankton than were found in higher latitudes within the tropics and sub-tropics (Graham, 1941).

The existence of the divergence at or near the Equator, with resultant upwelling of nutrient-rich water, is substantiated by the researches of this laboratory. The nature of the upwelling and the causal forces involved are discussed by Cromwell (1951 and 1953) and Sette (MS). Apparently the strong east and southeast trade winds which prevail for the greater part of the year and the effect of the Coriolis force are the major influences governing this equatorial current system.

Basic nutrients, brought to the surface by the equatorial upwelling, are essential to the growth of phytoplankton; in the present studies the concentration of dissolved inorganic phosphate is used as an indicator of these nutrients. Figure 3A shows the variation in inorganic phosphate with latitude, as found on seven cruises in the central Pacific. We have no empirical explanation at the present time for the asymmetric distribution of phosphate with respect to the Equator. This may be related, however, to differences in the meridional components of the surface current in the region of the Equator, or perhaps to differences in the rate of utilization by phytoplankton. As indicative of the phosphate $\longrightarrow$ phytoplankton $\longrightarrow$ zooplankton eutrophic linkage, we have found a highly significant positive correlation between zooplankton and inorganic phosphate on the long north-south sections crossing the Equator (King and Demond, 1953).

The frequently appearing " fronts " (Cromwell, 1953) in the zone of convergence north of the Equator, at 2° to 4° N. latitude, may also contribute to the apparent greater abundance of life in the equatorial region. Floating organisms of high buoyancy may tend to congregate along the fronts just as driftwood does along a " current rip." Motile plankton forms capable of resisting the downward currents would also tend to concentrate in the surface waters; thus a rich pasturage for plankton-feeding animals could result.

The unusual abundance of marine life in the region of the Equator and the Countercurrent has been observed by many expeditions and world travellers while crossing the Pacific. The surface manifestations of the enrichment may have a counterpart in certain features of the bottom deposits of this area of the Pacific. Revelle (1944) points out the agreement between the southern boundary of the Countercurrent and the northern border of the Pacific *Globigerina* ooze area. Arrhenius

(1950) concluded from an examination of bottom samples collected by the Swedish Deep-Sea Expedition that in the Pacific the "biogenous component" increases strongly in the region between the Equator and the southern boundary of the Countercurrent "—where a biolith, rich in fossils of foraminifera, radiolaria and diatoms is thus deposited."

From October, 1950, to June, 1953, the Pacific Oceanic Fishery Investigations conducted experimental longline fishing for tuna on 10 cruises in waters of the equatorial Pacific. The fishing took place in essentially the same area with about the same boundaries of latitude and longitude as our plankton investigations. The longline method of fishing and the results obtained on these cruises have been reviewed by Murphy and Shomura (1953*a* and 1953*b*).

In the Pacific, several species of tuna are taken by the longline fishing method. In the equatorial central Pacific the yellowfin, *Neothunnus macropterus* (Temminck and Schlegel), constitutes by far the largest percentage of the catch. When the catches, in terms of yellowfin captured per hundred hooks fished at each station, are combined in 5-degree intervals of latitude, irrespective of longitude and time of sampling—as was done for the zooplankton to produce Figure 3B — the result (Fig. 3C) indicates the area of best catch to be at 4°N.—0° latitude. The average catch rate drops off very fast to the north and south of these latitudes.

It is rather obvious that there is more than a casual relationship between zooplankton and yellowfin tuna, but, as might be expected when using the average values of zooplankton and fish from a number of disconnected cruises, the latitudinal distribution of zooplankton and fish do not precisely correspond. There are several reasons why this might be so, but for the present discussion it is enough to establish that one of the basic food constituents of tuna — plankton — reaches a peak of abundance near the Equator in a region high in mineral nutrients and that this same region is also found to contain maximal concentrations of yellowfin tuna.

In summary it would seem that upwelling at the Equator, resulting from the equatorial divergence, replenishes the supply of nutrients in the surface waters and provides a suitable environment for the growth of phytoplankton. Since animal life depends on its food supply, conditions in this region are favourable for the development of a zooplankton population. Convergence in the surface water layers, occurring usually at 2° to 4° N. latitude, between the Equator and the southern boundary of the Countercurrent, tends to concentrate the zooplankton into a rich pasturage for forage orga These in turn serve as food for the larger such as the tunas. Thus, a productive c the sea, starting from upwelled equatorial results in the formation of a vast potentia resource in the form of yellowfin tuna.

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Table 1

Cruise period, general area visited, and number of zooplankton samples collected on 10 cruises of the U.S. Fish and Wildlife Service vessel *Hugh M. Smith* during the years 1950 to 1952.

uise	Cruise period	Approximate longitude	Range of latitude	Number of samples
2	Jan.-Feb. 1950	170°W	23°N-4°S	12
	Feb.-Mar. 1950	160°W	19°N-4°S	12
5	June 1950	180°	27°N	1
	July 1950	170°W	25°N-5°S	26
	July-Aug. 1950	160°W	20°N-4°S	24
7	Oct.-Nov. 1950	160°W	20°N-2°N	23
	Nov. 1950	170°W	6°N	1
8	Jan. 1951	150°W	6°N	1
	Jan.-Feb. 1951	160°W	20°N-7°S	41
	Feb.-May 1951	170°W	20°N-14°S	45
9	June 1951	180°	25°N	1
	June 1951	170°W	22°N-4°S	13
	June 1951	160°W	20°N-1°S	11
1	Sept. 1951	150°W	19°N-4°S	45
	Sept. 1951	160°W	2°N-1°N	5
4	Jan.-Feb. 1952	150°W	7°N-3°S	7
	Jan.-Feb. 1952	160°W	1°N-6°S	9
	Mar. 1952	170°W	6°N-5°S	13
	Mar. 1952	180°	9°N-8°S	18
5	May-June 1952	140°W	9°N-7°S	60
6	Aug. 1952	150°W	2°N-3°S	14
8	Oct. 1952	120°W	7°N-8°S	13
	Nov. 1952	130°W	9°N-4°S	10

Table 2

iation in zooplankton abundance as associated with latitude and longitude without regard to time of year of sampling. es given are means of zooplankton volumes (as cc per 1000m³ of water strained). [Number of samples for each area ed in parentheses.]

	180°	170°	160°	150°	140°	130°	120°	Mean
25°N	12.5(2)	27.1(1)	..	..	..	..	..	17.4(3)
20°	..	16.5(6)	24.6(4)	..	..	..	..	19.8(10)
15°	..	21.6(8)	31.7(10)	16.4(3)	..	..	..	25.7(21)
10°	..	14.7(13)	22.0(21)	20.1(8)	..	..	..	19.4(42)
5°	19.6(5)	23.8(19)	30.6(31)	26.8(13)	51.2(18)	37.3(3)	41.8(2)	32.6(91)
0°	27.2(5)	37.0(24)	37.0(34)	37.7(28)	34.8(17)	35.8(4)	38.2(6)	36.5(118)
5°	25.9(4)	32.6(28)	36.8(20)	39.9(15)	38.9(19)	34.2(3)	37.9(3)	35.9(92)
0°	15.4(4)	20.8(8)	28.7(5)	..	21.8(6)	..	29.6(2)	22.5(25)
4°S	..	16.5(3)	..	..	..	..	..	16.5(3)
	24.1(14)	31.7(71)	34.6(85)	35.8(56)	41.7(54)	35.8(10)	38.8(11)	

* For latitudes 9°N to 4°S only.

Table 3.

Variation in zooplankton abundance with latitude as obtained on four major cruises of the *Hugh M. Smith.* Va
given are mean zooplankton volumes (as cc per 1000m³ of water strained). [Number of samples for each area inclu
in parentheses].

Latitude	Cruise 2		Cruise 5		Cruise 8		Cruise 11	
	Feb. 1950		July 1950		Feb.-Mar. 1951		Sept. 1951	
	170°	160°	170°	160°	170°	160°	150° Section 1	150° Sectio
24°-20°N	10.8(2)	..	21.4(2)	28.9(1)	14.5(1)	15.4(1)	..	
19°-15°	..	17.6(1)	25.9(3)	28.6(2)	14.2(3)	10.5(1)	..	16.
14°-10°	11.2(3)	6.6(3)	20.4(4)	23.3(6)	12.5(5)	19.7(5)	17.0(3)	22.
9°-5°	23.1(2)	26.4(3)	25.4(6)	43.2(5)	21.0(6)	23.4(12)	24.4(5)	31.
4°-0°	53.2(2)	74.0(2)	42.0(4)	62.2(4)	35.4(12)	24.7(15)	41.6(10)	45.
0°-4°	53.7(3)	57.7(3)	53.8(5)	36.5(6)	21.4(8)	36.8(4)	45.6(5)	58.
5°-9°	..	..	31.5(1)	..	19.3(7)	34.1(3)	..	
10°-14°S	..	..	..	..	16.5(3)	..	..	

Table 4.

Variation in zooplankton abundance with longitude and time of year of sampling for certain latitudinal zones. V
are mean zooplankton volumes (as cc per 1000m³ of water strained). [Number of samples for each area and season enc
in parentheses].

	Jan.-Feb.-Mar.	Apr.-May-June	July-Aug.-Sept.	Oct.-Nov.-Dec.	
4°N-0°					
180°	27.2(5)	..	..	..	27.
170° W	36.8(19)	20.1(1)	42.0(4)	..	37
160°	29.2(19)	27.7(3)	46.4(9)	68.0(3)	37.
150°	25.0(3)	..	39.3(25)	..	37.
140°	..	34.8(17)	..	..	34.
130°	..	..	..	35.8(4)	35.
120°	..	..	..	38.2(6)	38.
Mean	31.8	33.1	41.2	44.3	
0°-4°S					
180°	25.9(4)	..	..	..	25.
170° W	27.5(17)	29.2(6)	53.8(5)	..	32.
160°	38.5(12)	27.6(2)	36.5(6)	..	36.
150°	26.3(1)	..	40.9(14)	..	39.
140°	..	38.9(19)	..	..	38.
130°	..	..	..	34.2(3)	34.
120°	..	..	..	37.9(3)	37.
Mean	31.2	35.9	42.4	36.1	
9°N-4°S					
180°	24.1(14)	..	..	..	24.
170° W	30.2(46)	27.8(9)	39.3(15)	19.2(1)	31.
160°	29.9(46)	28.7(7)	42.6(20)	42.8(12)	34.
150°	25.4(8)	..	37.5(48)	..	35.
140°	..	41.7(54)	..	..	41.
130°	..	..	..	35.8(10)	35.
120°	..	..	..	38.8(11)	38.
Mean	29.0	38.6	39.1	38.7	

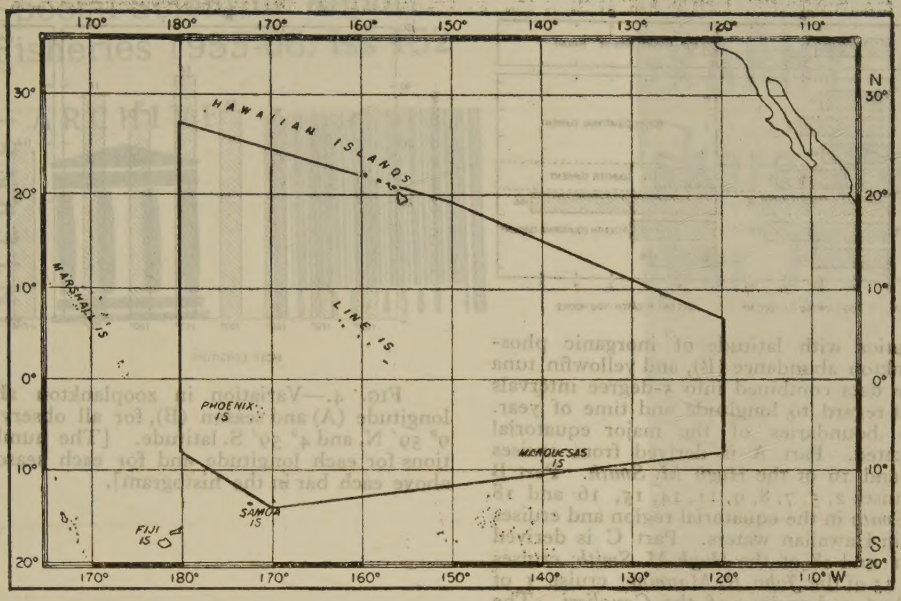

FIG. 1.—Map of the central Pacific showing the boundaries of the area covered in these investigations.

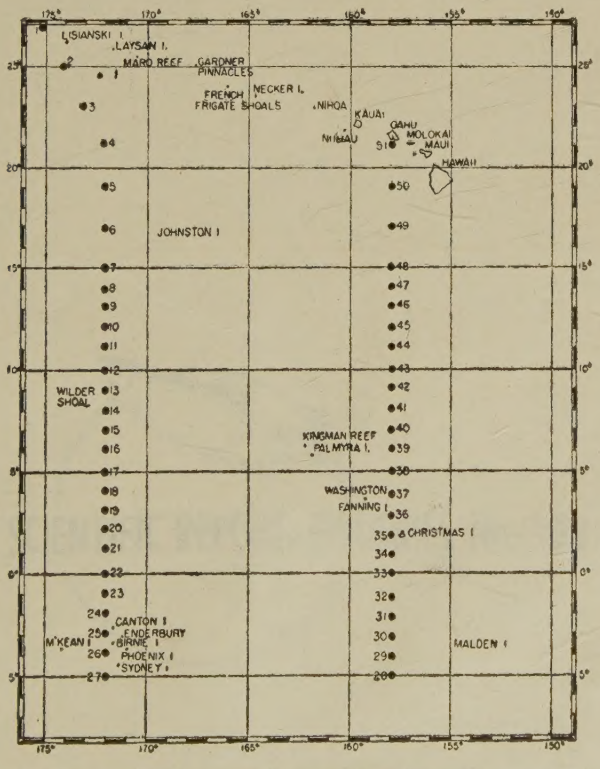

FIG. 2.—Plankton station positions for cruise 5 of the *Hugh M. Smith*, showing the station pattern of one of the combined hydrographic and plankton cruises.

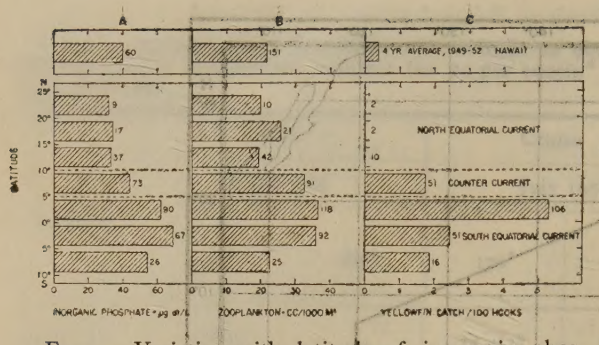

FIG. 3.—Variation with latitude of inorganic phosphate (A), zooplankton abundance (B), and yellowfin tuna catch (C), with the data combined into 5-degree intervals of latitude without regard to longitude and time of year. The approximate boundaries of the major equatorial currents are indicated. Part A is derived from cruises 2, 5, 8, 11, 14, 15 and 16 of the *Hugh M. Smith*. Part B is derived from cruises 2, 5, 7, 8, 9, 11, 14, 15, 16 and 18 of the *Hugh M. Smith* in the equatorial region and cruises 10, 12, 17 and 20 in Hawaiian waters. Part C is derived from cruises 7, 11 and 18 of the *Hugh M. Smith*; cruises 11, 12, 13, 14 and 15 of the *John R. Manning*; cruise 1 of the *Charles H. Gilbert* and cruise 1 of the *Cavalieri*. The vessels *Smith*, *Manning* and *Gilbert* are the property of the U.S. Fish and Wildlife Service. The vessel *Cavalieri* was chartered by the Government for this one fishing cruise. [The number of observations for each interval of latitude is indicated after each bar in the histogram.]

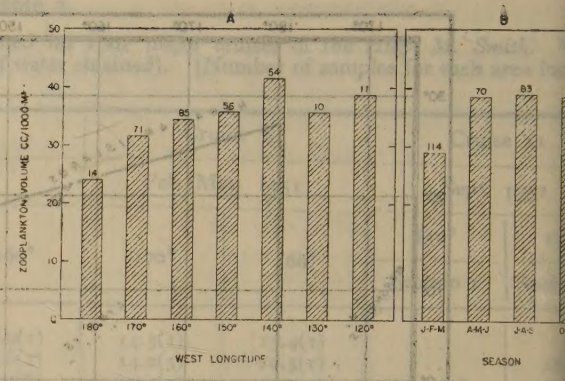

FIG. 4.—Variation in zooplankton abundance longitude (A) and season (B), for all observations betv 9° 59′ N. and 4° 59′ S. latitude. [The number of obse tions for each longitude and for each season is indic above each bar in the histogram].